AWS C1.1M/C1.1:2019
An American National Standard

Recommended Practices for Resistance Welding

American Welding Society®

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An American National Standard

Approved by
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Recommended Practices for Resistance Welding

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Prepared by the
American Welding Society (AWS) C1 Committee on Resistance Welding

Under the Direction of the
AWS Technical Activities Committee

Approved by the
AWS Board of Directors

Abstract

This Recommended Practices is a collection of data and procedures that are intended to assist the user in setting up resistance welding equipment to produce resistance welded production parts. While the recommendations included are not expected to be final procedures for every production part or every welding machine, they serve as starting points from which a user can establish acceptable welding machine settings for specific production welding applications.

In some cases, recommended machine data is not available. In these instances, some description of the process is given to assist the reader in determining if the process might be suitable for the application.

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This standard is subject to revision at any time by the AWS C1 Committee on Resistance Welding. It must be reviewed every five years, and if not revised, it must be either reaffirmed or withdrawn. Comments (recommendations, additions, or deletions) and any pertinent data that may be of use in improving this standard are requested and should be addressed to AWS Headquarters. Such comments will receive careful consideration by the AWS C1 Committee on Resistance Welding and the author of the comments will be informed of the Committee's response to the comments. Guests are invited to attend all meetings of the AWS C1 Committee on Resistance Welding to express their comments verbally. Procedures for appeal of an adverse decision concerning all such comments are provided in the Rules of Operation of the Technical Activities Committee. A copy of these Rules can be obtained from the American Welding Society, 8669 NW 36 St, # 130, Miami, FL 33166.

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Foreword

This foreword is not part of this standard, but is included for informational purposes only.

The data contained in these Recommended Practices have been compiled by the AWS Committee on Resistance Welding, by reviewing the data in the previous documents, by canvassing users of the resistance welding processes and correlating the data thus obtained. The resulting welding schedules shown in the tables were circulated for comments and, in addition, some tests were conducted to ascertain that welds of the specified strengths could be obtained.

The present edition of Recommended Practices represents an updated combination and extension of data presented in the previous edition of AWS C1.1M/C1.1:2012, *Recommended Practices for Resistance Welding*. Practices for new materials have been added and practices for materials which are not currently resistance welded in commercial production have been deleted. The new materials include high-strength low-alloy steels, both coated and uncoated.

The AWS C1 Committee on Resistance Welding has prepared these Recommended Practices in the hope that they will serve as an incentive for industry to develop methods and procedures improving upon the practice presented herein; which will permit the raising of quality and performance standards. If this is achieved, the Committee will have been amply repaid for the time and effort it has devoted to this work.

A vertical line in the margin and underlined text in clauses, tables, or figures indicates an editorial or technical change from the 2012 edition.

Comments and suggestions for the improvement of this standard are welcome. They should be sent to the Secretary, AWS C1 Committee on Resistance Welding, American Welding Society, 8669 NW 36 St, Miami, FL 33166.

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Recommended Practices for Resistance Welding

1. General Requirements

1.1 Scope. It is the intent of this publication to present current concepts and practices for resistance welding (and related processes) of ferrous and nonferrous metals including coated and dissimilar metals. Where practical, welding schedules are included. In other instances where schedules are too varied or the state-of-the-art is not sufficiently developed, descriptive guidelines are included to enable the user to establish welding procedures to meet its requirements.

It is important to recognize that these recommended practices are not the only means to weld the materials and thickness shown. When developing a welding schedule(s) for a particular application, the workpiece geometry, equipment employed, and production requirements will all influence the parameters and effectiveness of the process.

In using the data shown in the tables, it is imperative that reference be made to the appropriate text. Failure to refer to the text may result in misinterpretation of the data in the tables. The text has been kept as brief as possible and all extraneous comments have been omitted.

For more detailed information on the fundamentals of the resistance welding processes and the types of equipment utilized for the different processes, consult the current AWS *Welding Handbook*.

1.2 Units of Measurement. This standard makes use of both the International System of Units (SI) and U.S. Customary Units. The latter are shown within brackets [ ] or in appropriate columns in tables and figures. The measurements may not be exact equivalents; therefore, each system shall be used independently.

1.3 Safety. Safety and health issues and concerns are beyond the scope of this standard, and therefore are not fully addressed herein.

Safety and health information is available from the following sources:

American Welding Society:

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*;

AWS Safety and Health Fact Sheets; and

Other safety and health information on the AWS website.

Material or Equipment Manufacturers:

Safety Data Sheets supplied by materials manufacturers

Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies:

Work performed in accordance with this standard may involve the use of materials having been deemed hazardous, and may involve operations or equipment which may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply.

AWS standards:

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*.

3. Terms and Definitions

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*, provides the basis for terms and definitions used herein. However, the following terms and definitions are included below to accommodate usage specific to this document.

advanced high-strength steels (AHSS). A class of steels including dual phase (DP) and transformation-induced plasticity (TRIP) steels. AHSS grades have a minimum tensile strength of 500 MPa [72 ksi] and possess high ductility compared to HSLA steels of similar strength. The properties of these steels are achieved through the addition of alloying elements and control of microstructure.

bake hardenable steel. Low-carbon steel having the capability of being strengthened during a subsequent paint baking process.

coated steels. These steels have a metallic, inorganic, or organic coating applied for corrosion protection, decoration, or other application consideration such as lubricity or conductivity. Virtually all coating will have an influence on the resistance welding process.

dent-resistant steel. A general term for low-carbon steels having higher resistance to plastic deformation than the standard cold-rolled, low yield, and low-carbon steels. It encompasses HSLA, bake hardenable, and dual-phase steels.

high-strength low-alloy (HSLA) steel. A general term for low-alloyed steel having yield strength higher than typical 350 MPa [50 ksi] yield strength low-carbon steels. It can be furnished as either a hot- or cold-rolled product.

high-strength steels (HSS). A general term for steels with minimum tensile strength greater than 350 MPa [50 ksi].

interstitial-free (I-F) steels. A group of steels having very low levels of interstitial elements. Carbon and nitrogen are generally limited to 0.005% maximum. These steels have excellent formability and are widely used in the automotive and appliance industries.

minimum weld spacing. The center-to-center distance between adjacent welds beyond which no increase in welding current is necessary to compensate for current shunting effects.

minimum contact overlap. The minimum distance to contain a weld with respect to the edge of the material to be joined.

mushrooming. The deformation or bulging of an electrode at the contact surface with the workpiece, as a result of the various actions during the weld.

weld discrepancy. A weld condition deviating from the applicable standard, specification, or engineering drawing.

weld lobe. The current, time, and force ranges which provide acceptable welds.

4. Resistance Spot and Seam Welding

4.1 Uncoated Carbon and Low-Alloy Steels

4.1.1 Introduction

4.1.1.1 Low-Carbon Steels. Low-carbon steels contain less than 0.20% carbon and less than 0.50% manganese, with the remaining alloying elements totaling less than 1%. The maximum hardness attainable in carbon and low-alloy steels is dependent almost exclusively on the carbon content. In addition to this effect on maximum hardness, carbon has a relatively strong influence on the depth or ease of hardening, otherwise known as hardenability. Manganese also combines with sulfur and reduces the tendency toward hot-cracking. Hot-cracking results from the low strength of the steel at high temperatures. The steel cannot accommodate the stresses which develop during cooling, and cracks form in the weld metal or in the heat-affected zone (HAZ).

Low-carbon steels have typical bulk electrical resistivities (i.e., the specific electrical resistivity of a given volume of metal) of 10–20 μΩ-cm [4–8 μΩ-in], and have large plastic ranges. Both of these characteristics make low-carbon steel quite weldable using resistance welding processes. However, weld- and heat-affected zones in low-carbon steel welds with carbon levels greater than 0.13% may be susceptible to hardening due to rapid cooling during welding; therefore, the rapid cooling rates of resistance spot and seam welding are of concern for steels containing these levels of carbon. In this carbon range, precautions as described for medium and high-carbon steels may be required.

Several new designations of low-carbon steels have been incorporated into the nomenclature of the industry. These include bake-hardenable, dent-resistant, and interstitial-free (I-F) steels. Dent-resistant materials are defined as low- carbon steels that have higher resistance to plastic deformation than do the typical low-carbon steels. Dent-resistant steels have higher yield strength than typical steels. The yield strength increases during the paint bake cycle. The magnitude of this increase depends on the degree of deformation in the forming process. Deformation triggers the hardening effect; however, the increases in strength due to cold forming and the increases in strength due to heat treatment are not cumulative. This increase in strength due to heat treatment during the paint bake cycle is known as bake hardening.

Many of the new AHS steels exhibit this property, for example, the dual phase steels. I-F steels are low-carbon steels that have less than 0.005% carbon with niobium (columbium) and titanium additions to improve formability. Welding of these materials is similar to most low-carbon steels, and similar welding schedules can be used.

4.1.1.2 Medium-Carbon and Alloy Steels. Medium-carbon steels contain 0.20–0.55% carbon with the remaining alloying elements totaling less than 1.0%. Steels are considered to be alloy steels when the maximum of the range given for the content of alloying elements exceeds one or more of the following limits: manganese, 1.65%; silicon, 0.60%; copper, 0.60%; and/or when a definite range or definite minimum quantity of other alloying elements is specified or required within the limits of the recognized field of constructional alloy steels: aluminum, and chromium up to 9%; cobalt, niobium, molybdenum, nickel, titanium, tungsten, vanadium, zirconium, or any other alloying element added to obtain a desired alloying effect.

Higher carbon levels represent higher hardenability, and care is required when welding these steels. For this reason, medium-carbon steels have an increased tendency toward embrittlement than do low-carbon steels. However, high hardness does not always mean embrittlement. A more important indicator of embrittlement than the absolute value of the hardness will be its increase relative to the hardness of the material before welding. Medium-carbon and alloy steels frequently require preheating prior to, and tempering treatments after, welding. These steels may be heat treated on welding equipment with the necessary controls, or heat treated as a separate operation.

4.1.1.3 High-Carbon Steels. High-carbon steels contain more than 0.55% and less than 1.50% carbon. These steels have high hardenability and are not easily resistance welded without weld cracking. Special procedures must be used when resistance welding these steels.

4.1.1.4 HSLA Steels. High-strength, low-alloy (HSLA) steels obtain their strength and other mechanical properties through the addition of alloying elements, or through thermal processing, or both. Steels may be weldable with themselves, however, in some cases, these steels may not be weldable in combination with other steels. When welding HSLA steels, welding schedules may include preweld heat conditioning, or postweld heat treatment to improve the microstructure of the weld nugget, HAZ, or both.

4.1.1.5 AHSS. Advanced High Strength Steels (AHSS) is a family of HSS introduced since the early 2000s for various automotive applications. These steels differ from HSLA steels; they do not necessarily contain microalloying elements. Instead, the required strength and ductility are achieved through a combination of additional major alloying elements (such as manganese, chromium, molybdenum) and precise control of the steel microstructure. AHSS grades have a minimum tensile strength of 500 MPa [72 ksi] and are commercially available from 500 to 1000 MPa [72–145 ksi]. AHSS grades include Dual Phase (DP) and Transformation-Induced Plasticity (TRIP) steels. The steels are available both in coated and uncoated conditions. Steels with minimum tensile strength up to 1000 MPa [145 ksi] have shown to be readily weldable without pre or postweld heating. Tables 55 and 56 provide starting spot-weld parameters for AC welding machines, while Tables 57 and 58 provide the parameters for MFDC welding machines.

4.1.2 Surface Conditions. Prior to welding, the workpiece surface should be free of contaminants which might adversely affect the weld quality. Surface contaminants and organic coatings can adversely affect the chemical composition and quality of the weld.

Rust has an adverse effect on weld quality. The presence of rust on steel surface increases surface resistance during welding and can lead to expulsion of weld metal due to high heat development.

Uncoated steel is typically classified as either hot-rolled or cold-rolled. The hot-rolled product is supplied in two conditions, hot-rolled, or pickled, and oiled. Hot-rolled steel sheet develops a tenacious mill scale which has a very high contact resistance. Cold-rolled and hot-rolled, pickled, and oiled steel sheets do not exhibit mill scale because the mill scale is removed during the material processing. Low-carbon and HSLA steel sheets are typically supplied in both the hot-rolled, pickled, and oiled, and cold-rolled conditions. Materials in these conditions are weldable as long as surface contaminants are minimized.

4.1.3 Welding Parameters. The data shown in the tables is offered as a guide to develop welding schedules for weldable materials. Welding parameters in these tables should be considered as starting points for the development of actual production schedules. The optimum welding schedules may vary with different applications and with different machines.

The following subclauses are comments and discussions pertaining to the welding parameter data in these tables. Additional comments and discussions applicable to carbon and low-alloy steels as well as other metals are presented separately in 4.7.

Table 1
Spot-Welding Parameters for Bare, Galvanneal, and Galvanized Low-Carbon Steel <350 MPa [72 ksi] Ultimate Tensile Strength[a, b, c, d]

Metal Thickness[e] mm [in]	Electrode[f] Face Dia. mm [in]	Electrode[f] Shape[g]	Net Electrode Force kN [lb]	Coated Weld[h] Time Cycles	Coated Weld[h] Time ms	Bare Weld[h] Time Cycles	Bare Weld[h] Time ms	Coated Weld[i] Current (Approx) Amps	Bare Weld[i] Current (Approx) Amps	Minimum Contact Overlap mm [in]	Minimum Weld Spacing mm [in]	Nugget Diameters[j] Minimum Satisfactory mm [in]	Nugget Diameters[j] Setup mm [in]
0.51 [0.020]	4.76 [0.187]	A,B,E	1.78 [400]	10	166	7	116	10 900	8 500	11.2 [0.44]	9.5 [0.37]	3.0 [0.12]	4.6 [0.18]
0.64 [0.025]	4.76 [0.187]	A,B,E	2.00 [450]	11	183	8	133	11 500	9 500	11.9 [0.47]	15.9 [0.63]	3.3 [0.13]	4.6 [0.18]
0.76 [0.030]	6.35 [0.250]	A,B,E	2.22 [500]	12	200	9	150	12 300	10 500	11.9 [0.47]	15.9 [0.63]	3.6 [0.14]	5.1 [0.20]
0.89 [0.035]	6.35 [0.250]	A,B,E,F	2.67 [600]	13	216	9	150	13 500	11 500	13.5 [0.53]	19.0 [0.75]	4.1 [0.16]	6.4 [0.25]
1.02 [0.040]	6.35 [0.250]	A,B,E,F	3.11 [700]	14	233	10	166	14 100	12 500	13.5 [0.53]	19.0 [0.75]	4.3 [0.17]	6.4 [0.25]
1.14 [0.045]	6.35 [0.250]	A,B,E,F	3.34 [750]	15	250	11	183	14 800	13 000	15.0 [0.59]	20.3 [0.94]	4.8 [0.19]	6.4 [0.25]
1.27 [0.050]	7.94 [0.313]	A,B,E,F	3.56 [800]	16	266	12	200	15 600	13 500	15.0 [0.59]	20.3 [0.94]	5.1 [0.20]	7.9 [0.31]
1.40 [0.055]	7.94 [0.313]	A,B,E,F	4.00 [900]	17	283	13	216	16 200	14 000	16.0 [0.63]	27.0 [1.06]	5.3 [0.21]	7.9 [0.31]
1.52 [0.060]	7.94 [0.313]	A,B,E,F	4.45 [1 000]	18	300	14	233	17 000	15 000	16.0 [0.63]	27.0 [1.06]	5.6 [0.22]	7.9 [0.31]
1.78 [0.070]	7.94 [0.313]	A,B,E,F	5.34 [1 200]	22	366	16	266	18 800	16 000	16.8 [0.66]	30.0 [1.18]	6.1 [0.24]	7.9 [0.31]
2.03 [0.080]	7.94 [0.313]	A,B,E,F	6.23 [1 400]	25	416	18	300	19 600	17 000	18.3 [0.72]	34.9 [1.37]	6.6 [0.26]	7.9 [0.31]
2.29 [0.090]	9.52 [0.375]	A,B,E,F	7.72 [1 600]	31	516	20	333	20 400	18 000	19.8 [0.78]	39.7 [1.56]	6.9 [0.27]	9.5 [0.37]
2.67 [0.105]	9.52 [0.375]	A,B,E,F	8.01 [1 800]	35	583	23	383	22 000	19 500	21.3 [0.84]	42.7 [1.68]	7.1 [0.28]	9.5 [0.37]
3.05 [0.120]	9.52 [0.375]	A,B,E,F	9.34 [2 100]	42	700	26	433	24 000	21 000	22.4 [0.88]	46.0 [1.81]	7.6 [0.30]	9.5 [0.37]

Note: The parameters shown represent a starting point from which a weld schedule can be established.

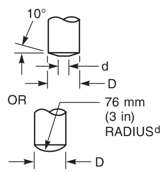
[a] Use of coated parameters recommended with the presence of a coating at any faying surface.
[b] These recommendations are based on available weld schedules representing recommendations from resistance welding equipment suppliers and users.
[c] For intermediate thicknesses parameters may be interpolated.
[d] Minimum weld button shear strength determined as follows:

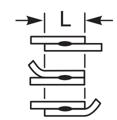
$$ST = \frac{(-6.36 \times 10^{-7} \times S^2 + 6.58 \times 10^{-4} \times S + 14.674) \times S \times 4 \times t^{1.5}}{1000}$$

ST = Shear Tension Strength (kN)
S = Base Metal Tensile Strength (MPa)
t = Material Thickness (mm)

[e] Metal thicknesses represent the actual thickness of the sheets being welded. In the case of welding two sheets of different thicknesses, use the welding parameters for the thinner sheet.
[f] Welding parameters are applicable when using electrode materials included in RWMA classes 1, 2, and 20.
[g] Electrode shapes listed include: A-pointed, B-domed, E-truncated, F-radiused. Figure 2 shows these shapes.
– The use of Type-B geometry may require a reduction in current and may result in excessive indentation unless face is dressed to specified diameter.
– The use of Type-F geometry may require an increase in current.
[h] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz equipment, multiply the weld times shown in cycles by 0.83, then round down to the nearest whole number.
[i] For DC welding equipment, lower current settings may be appropriate.
[j] Nugget diameters are listed as:
– the minimum diameter that is recommended to be considered a satisfactory weld.
– the initial aim setup nugget diameter that is recommended in setting-up a weld station to produce nuggets that consistently surpass the satisfactory weld nugget diameter for a given number of production welds.

Table 2
Pulsation Spot-Welding Parameters for Low-Carbon Steel[a],[b]





Combination of Thicknesses to be Welded mm [in]		Electrode Diameter[c] and Shape, Min d = 6.4 mm [0.25 in]: "D"[e] Min mm [in]	"d" Max. mm [in]	Net Electrode Force N [lb]	Weld Time[f] — On 20 [333] Cycles [ms], Off 5 [83] Cycles [ms] — Number of Pulsations: Single Welds	Adjacent Welds[g] 25–51 mm [1–2 in]	Adjacent Welds[g] 51–102 mm [2–4 in]	Current Approx. Amps	Minimum Contact Overlap mm [in]	Minimum Shear Strength kN [lb]	Nugget Diameter mm [in]: Minimum Satisfactory	Nugget Diameter mm [in]: Setup
3.18 to 3.18	[0.125 to 0.125]	25 [1.00]	11.1 [0.44]	8.0 [1 800]	3	5	4	18 000	22.2 [0.87]	22 [5 000]	9.5 [0.37]	11.4 [0.45]
3.18 to 4.76	[0.125 to 0.187]	25 [1.00]	11.1 [0.44]	8.0 [1 800]	3	5	4	18 000	22.2 [0.87]	22 [5 000]	9.5 [0.37]	11.4 [0.45]
3.18 to 6.35	[0.125 to 0.250]	25 [1.00]	11.1 [0.44]	8.0 [1 800]	3	5	4	18 000	22.2 [0.87]	22 [5 000]	9.5 [0.37]	11.4 [0.45]
4.76 to 4.76	[0.187 to 0.187]	32 [1.25]	12.7 [0.50]	8.7 [2 000]	6	20	14	19 500	28.6 [1.13]	44 [10 000]	12.7 [0.50]	15.2 [0.60]
4.76 to 6.35	[0.187 to 0.250]	32 [1.25]	12.7 [0.50]	8.7 [2 000]	6	20	14	19 500	28.6 [1.13]	44 [10 000]	12.7 [0.50]	15.2 [0.60]
4.76 to 7.94	[0.187 to 0.313]	32 [1.25]	12.7 [0.50]	8.7 [2 000]	6	20	14	19 500	28.6 [1.13]	44 [10 000]	12.7 [0.50]	15.2 [0.60]
6.35 to 6.35	[0.250 to 0.250]	32 [1.25]	14.3 [0.56]	9.6 [2 200]	12	24	18	21 500	34.9 [1.37]	67 [15 000]	14.3 [0.56]	17.8 [0.70]
6.35 to 7.94	[0.250 to 0.313]	32 [1.25]	14.3 [0.56]	9.6 [2 200]	12	24	18	21 500	34.9 [1.37]	67 [15 000]	14.3 [0.56]	17.8 [0.70]
7.94 to 7.94	[0.313 to 0.313]	38 [1.50]	15.9 [0.63]	10.7 [2 400]	15	30	23	24 000	38.1 [1.50]	89 [20 000]	15.9 [0.63]	17.8 [0.70]

Note: The parameters shown represent a starting point from which a weld schedule can be established.

[a] Type of steel—yield strength less than 480 MPa [70ksi].

[b] For DC welding equipment, lower current settings may be appropriate.

[c] Electrode material: RWMA Class 1, 2, or 20.

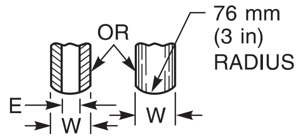
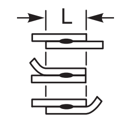
[d] For the 76 mm [3 in] radius face electrodes, the face diameter is the same as the electrode diameter.

[e] Electrode diameters are based on the following: ISO Standards 25, 32, and 38 mm; RWMA Standards 1.00, 1.25, and 1.50 in.

[f] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz equipment, multiply the weld times shown in cycles by 0.83, then round down to the nearest whole number.

[g] Adjacent welds are measured as centerline to centerline distance between welds.

Table 3
Seam-Welding Parameters for Bare, Galvanneal, and Galvanized Low-Carbon Steel >300 MPa [44 ksi] Ultimate Tensile Strength[a,b,c]

Thickness of the Thinnest Piece Metal Thickness mm [in]	Electrode[d,e,f] Width and Shape 		Bare Net Electrode Force kN [lb]	Coated Net Electrode Force kN [lb]	On Time		Off Time		Weld[h] Speed m/min mm [in]	Welds Per meter [inch]	Bare Current Amps	Coated Current Amps	Minimum[i] Contact Overlap mm [in] 
	W mm [in], min	E mm [in], max.			Cycles[g]	ms	Cycles[g]	ms					
0.25 [0.010]	10 [0.38]	4.6 [0.18]	1.8 [400]	2.2 [500]	2	33	1	16	2.0 [79]	590 [15]	8000	10 000	9.5 [0.37]
0.53 [0.021]	10 [0.38]	4.8 [0.19]	2.4 [550]	2.7 [600]	2	33	2	33	1.9 [75]	470 [12]	11 000	13 000	11.1 [0.44]
0.79 [0.031]	13 [0.50]	6.4 [0.25]	4.0 [900]	4.0 [900]	3	50	2	33	1.8 [71]	390 [10]	13 000	15 000	12.7 [0.50]
1.02 [0.040]	13 [0.50]	6.4 [0.25]	4.4 [980]	4.9 [1100]	3	50	3	50	1.7 [67]	350 [9]	15 000	17 000	12.7 [0.50]
1.27 [0.050]	13 [0.50]	7.9 [0.31]	4.7 [1050]	5.8 [1300]	4	66	3	50	1.7 [67]	310 [8]	16 500	19 000	14.3 [0.56]
1.57 [0.062]	13 [0.50]	7.9 [0.31]	5.3 [1200]	6.7 [1500]	4	66	4	66	1.6 [63]	280 [7]	17 500	21 000	15.9 [0.63]
1.98 [0.078]	16 [0.63]	9.5 [0.37]	6.7 [1500]	7.6 [1700]	6	100	5	83	1.4 [55]	240 [6]	19 000	22 500	17.5 [0.69]
2.38 [0.094]	16 [0.63]	11.1 [0.44]	7.6 [1700]	8.5 [1900]	7	116	6	100	1.3 [51]	220 [5.5]	20 000	24 000	19.0 [0.75]
2.77 [0.109]	19 [0.75]	12.7 [0.50]	8.7 [1950]	9.3 [2100]	9	150	6	100	1.2 [47]	200 [5]	21 000	25 000	20.6 [0.81]
3.18 [0.125]	19 [0.75]	12.7 [0.50]	9.8 [2200]	10.2 [2300]	11	183	7	116	1.1 [43]	180 [4.5]	22 000	26 000	22.2 [0.87]

Note: The parameters shown represent a starting point from which a weld schedule can be established.
[a] Use of coated parameters recommended with the presence of a coating at any faying surface.
[b] Material should be free from scale, oxides, paint, grease, and oil.
[c] For DC welding equipment, lower current settings may be appropriate.
[d] For the electrodes with a radius face, the face width is the same as the electrode width.
[e] Electrode materials: RWMA Class 1, 2, and 20.
[f] Electrode widths are based on the following: ISO Standards 10, 13, 16, and 19 mm; RWMA Standards 0.38, 0.48(0.50), 0.63, 0.75, 0.88, and 1.00 in.
[g] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz equipment, multiply the weld times shown in cycles by 0.83, then round down to the nearest whole number.
[h] Welding speeds noted do not give a leak-tight seam.
[i] For large assemblies, minimum contacting overlap indicated should be increased by 30 percent.

Table 4
Spot-Welding Parameters for Bare, Galvanneal, and Galvanized Low-Carbon Steel 350–700 MPa [50–108 ksi] Ultimate Tensile Strength[a,b,c,d,e]

Metal[f] Thickness mm [in]	Electrode[g]		Net Electrode Force kN [lb]	Coated Weld[i] Time		Bare Weld[i] Time		Coated Weld[e] Current (Approx) Amps	Bare Weld[e] Current (Approx) Amps	Minimum Contact Overlap mm [in]	Minimum Weld Spacing mm [in]	Nugget Diameters[j]	
	Face Dia. mm [in]	Shape[h]		Cycles	ms	Cycles	ms					Minimum Satisfactory mm [in]	Setup mm [in]
0.51 [0.020]	4.76 [0.187]	A,B,E	2.00 [500]	10	166	7	116	8 500	6 500	11.2 [0.44]	9.5 [0.37]	3.0 [0.12]	4.6 [0.18]
0.64 [0.025]	4.76 [0.187]	A,B,E	2.22 [600]	11	183	8	133	9 500	7 500	11.9 [0.47]	15.9 [0.63]	3.3 [0.13]	4.6 [0.18]
0.76 [0.030]	6.35 [0.250]	A,B,E	2.42 [650]	12	200	9	150	10 500	8 500	11.9 [0.47]	15.9 [0.63]	3.6 [0.14]	5.1 [0.20]
0.89 [0.035]	6.35 [0.250]	A,B,E,F	2.89 [700]	13	216	9	150	11 500	9 500	13.5 [0.53]	19.0 [0.75]	4.1 [0.16]	6.4 [0.25]
1.02 [0.040]	6.35 [0.250]	A,B,E,F	3.11 [800]	13	216	10	166	12 500	10 500	13.5 [0.53]	19.0 [0.75]	4.3 [0.17]	6.4 [0.25]
1.14 [0.045]	6.35 [0.250]	A,B,E,F	3.34 [900]	14	233	11	183	13 000	11 000	15.0 [0.59]	20.3 [0.94]	4.8 [0.19]	6.4 [0.25]
1.27 [0.050]	7.94 [0.313]	A,B,E,F	3.56 [1000]	16	266	12	200	13 500	11 500	15.0 [0.59]	20.3 [0.94]	5.1 [0.20]	7.9 [0.31]
1.40 [0.055]	7.94 [0.313]	A,B,E,F	4.56 [1100]	17	283	13	216	14 000	12 000	16.0 [0.63]	27.0 [1.06]	5.3 [0.21]	7.9 [0.31]
1.52 [0.060]	7.94 [0.313]	A,B,E,F	5.16 [1200]	18	300	14	233	15 000	13 000	16.0 [0.63]	27.0 [1.06]	5.6 [0.22]	7.9 [0.31]
1.78 [0.070]	7.94 [0.313]	A,B,E,F	5.60 [1400]	22	366	16	266	16 000	14 000	16.8 [0.66]	30.0 [1.18]	6.1 [0.24]	7.9 [0.31]
2.03 [0.080]	7.94 [0.313]	A,B,E,F	6.23 [1 600]	25	416	18	300	17 000	15 000	18.3 [0.72]	34.9 [1.37]	6.6 [0.26]	7.9 [0.31]
2.29 [0.090]	9.52 [0.375]	A,B,E,F	7.72 [2100]	31	516	20	333	18 000	15 000	19.8 [0.78]	39.7 [1.56]	6.9 [0.27]	9.5 [0.37]
2.67 [0.105]	9.52 [0.375]	A,B,E,F	8.01 [2250]	35	583	23	383	19 500	16 500	21.3 [0.84]	42.7 [1.68]	7.1 [0.28]	9.5 [0.37]
3.05 [0.120]	9.52 [0.375]	A,B,E,F	9.34 [2 100]	42	700	26	433	21 000	18 000	22.4 [0.88]	46.0 [1.81]	7.6 [0.30]	9.5 [0.37]

Note: The parameters shown represent a starting point from which a weld schedule can be established.

[a] Use of coated parameters recommended with the presence of a coating at any faying surface.

[b] These recommendations are based on available weld schedules representing recommendations from resistance welding equipment suppliers and users.

[c] For intermediate thicknesses parameters may be interpolated.

[d] Minimum weld button shear strength determined as follows:

$$ST = \frac{(-6.36 \times 10^{-7} \times S^{2} + 6.58 \times 10^{-4} \times S + 14.674) \times S \times 4 \times t^{1.5}}{1000}$$

ST = Shear Tension Strength (kN)
S = Base Metal Tensile Strength (MPa)
t = Material Thickness (mm)

[e] For DC welding equipment, lower current settings may be appropriate.

[f] Metal thicknesses represent the actual thickness of the sheets being welded. In the case of welding two sheets of different thicknesses, use the welding parameters for the thinner sheet.

[g] Welding parameters are applicable when using electrode materials included in RWMA classes 1, 2, and 20.

[h] Electrode shapes listed include: A-pointed, B-domed, E-truncated, F-radiused. Figure 2 shows these shapes.
– The use of Type-B geometry may require a reduction in current and may result in excessive indentation unless face is dressed to specified diameter.
– The use of Type-F geometry may require an increase in current.

[i] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz equipment, multiply the weld times shown in cycles by 0.83, then round down to the nearest whole number.

[j] Nugget diameters are listed as:
– the minimum diameter that is recommended to be considered a satisfactory weld.
– the initial aim setup nugget diameter that is recommended in setting-up a weld station to produce nuggets that consistently surpass the satisfactory weld nugget diameter for a given number of production welds.

Table 5
Spot-Welding Parameters for Bare, Galvanneal, and Galvanized Low-Carbon Steel >700 MPa [102 ksi] Ultimate Tensile Strength[a, b, c, d, e]

Metal[f] Thickness mm [in]	Electrode[g] Face Dia. mm [in]	Electrode[g] Shape[h]	Net Electrode Force kN [lb]	Coated Weld[i] Time Cycles	ms	Bare Weld[i] Time Cycles	ms	Coated Weld[j] Current (Approx) Amps	Bare Weld[j] Current (Approx) Amps	Minimum Contact Overlap mm [in]	Minimum Weld Spacing mm [in]	Nugget Diameters[e] Minimum Satisfactory mm [in]	Nugget Diameters[e] Setup mm [in]
0.51 [0.020]	4.76 [0.187]	A,B,E	2.00 [500]	12	200	8	133	7 500	5 500	11.2 [0.44]	9.5 [0.37]	3.0 [0.12]	4.6 [0.18]
0.64 [0.025]	4.76 [0.187]	A,B,E	2.22 [600]	13	216	10	166	8 500	6 500	11.9 [0.47]	15.9 [0.63]	3.3 [0.13]	4.6 [0.18]
0.76 [0.030]	6.35 [0.250]	A,B,E	2.42 [650]	14	233	11	183	9 500	7 500	11.9 [0.47]	15.9 [0.63]	3.6 [0.14]	5.1 [0.20]
0.89 [0.035]	6.35 [0.250]	A,B,E,F	2.89 [700]	15	250	11	183	10 500	8 500	13.5 [0.53]	19.0 [0.75]	4.1 [0.16]	6.4 [0.25]
1.02 [0.040]	6.35 [0.250]	A,B,E,F	3.11 [800]	16	266	12	200	11 500	8 500	13.5 [0.53]	19.0 [0.75]	4.3 [0.17]	6.4 [0.25]
1.14 [0.045]	6.35 [0.250]	A,B,E,F	3.34 [900]	17	283	13	216	12 000	10 000	15.0 [0.59]	20.3 [0.94]	4.8 [0.19]	6.4 [0.25]
1.27 [0.050]	7.94 [0.313]	A,B,E,F	3.56 [1000]	19	316	14	233	12 500	10 500	15.0 [0.59]	20.3 [0.94]	5.1 [0.20]	7.9 [0.31]
1.40 [0.055]	7.94 [0.313]	A,B,E,F	4.56 [1100]	20	333	16	266	13 000	11 000	16.0 [0.63]	27.0 [1.06]	5.3 [0.21]	7.9 [0.31]
1.52 [0.060]	7.94 [0.313]	A,B,E,F	5.16 [1200]	22	366	17	283	14 000	12 000	16.0 [0.63]	27.0 [1.06]	5.6 [0.22]	7.9 [0.31]
1.78 [0.070]	7.94 [0.313]	A,B,E,F	5.60 [1400]	26	433	19	316	15 000	13 000	16.8 [0.66]	30.0 [1.18]	6.1 [0.24]	7.9 [0.31]
2.03 [0.080]	7.94 [0.313]	A,B,E,F	6.23 [1 600]	30	500	21	350	16 000	14 000	18.3 [0.72]	34.9 [1.37]	6.6 [0.26]	7.9 [0.31]
2.29 [0.090]	9.52 [0.375]	A,B,E,F	7.72 [2100]	37	616	24	400	17 000	14 000	19.8 [0.78]	39.7 [1.56]	6.9 [0.27]	9.5 [0.37]
2.67 [0.105]	9.52 [0.375]	A,B,E,F	8.01 [2250]	42	700	28	466	18 500	15 500	21.3 [0.84]	42.7 [1.68]	7.1 [0.28]	9.5 [0.37]
3.05 [0.120]	9.52 [0.375]	A,B,E,F	9.34 [2400]	50	833	31	516	20 000	17 000	22.4 [0.88]	46.0 [1.81]	7.6 [0.30]	9.5 [0.37]

Note: The parameters shown represent a starting point from which a weld schedule can be established.

[a] Use of coated parameters recommended with the presence of a coating at any faying surface.

[b] These recommendations are based on available weld schedules representing recommendations from resistance welding equipment suppliers and users.

[c] For intermediate thicknesses parameters may be interpolated.

[d] Minimum weld button shear strength determined as follows:

$$ST = \frac{(-6.36 \times 10^{-7} \times S^2 + 6.58 \times 10^{-4} \times S + 14.674) \times S \times 4 \times t^{1.5}}{1000}$$

ST = Shear Tension Strength (kN)
S = Base Metal Tensile Strength (MPa)
t = Material Thickness (mm)

[e] Nugget diameters are listed as:
– the minimum diameter that is recommended to be considered a satisfactory weld.
– the initial aim setup nugget diameter that is recommended in setting-up a weld station to produce nuggets that consistently surpass the satisfactory weld nugget diameter for a given number of production welds.

[f] Metal thicknesses represent the actual thickness of the sheets being welded. In the case of welding two sheets of different thicknesses, use the welding parameters for the thinner sheet.

[g] Welding parameters are applicable when using electrode materials included in RWMA classes 1, 2, and 20.

[h] Electrode shapes listed include: A-pointed, B-domed, E-truncated, F-radiused. Figure 2 shows these shapes.
– The use of Type-B geometry may require a reduction in current and may result in excessive indentation unless face is dressed to specified diameter.
– The use of Type-F geometry may require an increase in current.

[i] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz equipment, multiply the weld times shown in cycles by 0.83, then round down to the nearest whole number.

[j] For DC welding equipment, lower current settings may be appropriate.

Table 6
Spot-Welding Parameters for Low-Alloy and Medium-Carbon Steels[a,b]

Material[c]			Electrode[d,e,f]				Weld[b] Time		Quench[b] Time		Temper[b] Time							
Type	Condition	Thickness mm [in]	D Min. Diameter mm [in]	d Face Diameter mm [in]	R Face Radius mm [in]	Net Electrode Weld and Temper Force kN [lb]	Cycles	ms	Cycles	ms	Cycles	ms	Weld[g] Current (Approx.) Amps	Temper[f] Current % of Expulsion Weld Current	Minimum Contacting Overlap mm [in]	Minimum[h] Weld Spacing mm [in]	Minimum Shear Strength kN [lb]	Satisfactory Nugget Diameter mm [in]
SAE 1020	Hot rolled	1.02 [0.040]	16 [0.63]	6.4 [0.25]	150 [6.0]	6.56 [1470]	6	100	17	283	6	100	16 000	90	13 [0.51]	25 [0.98]	6.05 [1360]	5.8 [0.23]
SAE 1035	Hot rolled	1.02 [0.040]	16 [0.63]	6.4 [0.25]	150 [6.0]	6.56 [1470]	6	100	20	333	6	100	14 200	91	13 [0.51]	25 [0.98]	6.94 [1560]	5.6 [0.22]
SAE 1045	Hot rolled	1.02 [0.040]	16 [0.63]	6.4 [0.25]	150 [6.0]	6.56 [1470]	6	100	24	400	6	100	13 800	88	13 [0.51]	25 [0.98]	8.90 [2000]	5.3 [0.21]
SAE 4130	Hot rolled	1.02 [0.040]	16 [0.63]	6.4 [0.25]	150 [6.0]	6.56 [1470]	6	100	18	300	6	100	13 000	90	13 [0.51]	25 [0.98]	9.43 [2120]	5.6 [0.22]
SAE 4340	Normalized & drawn	0.79 [0.031]	16 [0.63]	4.8 [0.19]	150 [6.0]	4.00 [900]	4	66	12	200	4	66	8 250	84	11 [0.43]	19 [0.75]	4.82 [1080]	4.1 [0.16]
SAE 4340	Normalized & drawn	1.59 [0.062]	19 [0.75]	7.9 [0.31]	150 [6.0]	8.90 [2000]	10	166	45	750	10	166	13 900	77	16 [0.63]	38 [1.50]	17.08 [3840]	6.9 [0.27]
SAE 4340	Normalized & drawn	3.18 [0.125]	25 [1.00]	15.9 [0.63]	254 [10.0]	24.47 [5500]	45	750	240	4000	90	1500	21 800	86	22 [0.87]	64 [2.52]	60.9 [13680]	14.0 [0.55]
SAE 8630	Normalized & drawn	0.79 [0.031]	13 [0.50]	4.8 [0. 19]	150 [6.0]	3.56 [800]	4	66	12	200	4	66	8650	88	11 [0.43]	19 [0.75]	5.43 [1220]	4.1 [0.16]
SAE 8630	Normalized & drawn	1.59 [0.062]	16 [.63]	7.9 [0.31]	150 [6.0]	80.17 [1800]	10	166	36	600	10	166	12 800	83	16 [0.63]	38 [1.50]	18.86 [4240]	6.9 [0.27]
SAE 8630	Normalized & drawn	3.18 [0.125]	25 [1.00]	15.9 [0.63]	254 [10.0]	20. 02 [4500]	45	750	210	3500	90	1500	21 800	84	22 [0.87]	64 [2.52]	58.72 [13 200]	14.0 [0.55]
SAE 8715	Normalized & drawn	0.46 [0.018]	13 [0.50]	3.2 [0.13]	150 [6.0]	1.56 [3500]	3	50	4	66	3	50	3900	85	11 [0.43]	16 [0.63]	1.78 [400]	2.5 [0.10]
SAE 8715	Normalized & drawn	1.59 [0.062]	16 [0.63]	7.9 [0.31]	150 [6.0]	7.12 [1600]	10	166	28	466	10	166	12 250	85	16 [0.63]	38 [1.50]	14.68 [3300]	6.9 [0.27]
SAE 8715	Normalized & drawn	3.18 [0.125]	25 [1.00]	15.9 [0.63]	254 [10.0]	20. 02 [4500]	45	750	180	3000	90	1500	22 700	85	22 [0.87]	64 [2.52]	56.76 [12 760]	14.0 [0.55]

Note: The parameters shown represent a starting point from which a weld schedule can be established.

[a] Data obtained from steel companies.
[b] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz equipment, multiply the weld times shown in cycles by 0.83, then round down to the nearest whole number.
[c] Material should be pickled or otherwise cleaned to obtain a surface contact resistance not exceeding 200 μΩ.
[d] Electrode Material: RWMA Class 1, 2, and 20.
[e] Electrode diameter and shape are the same for both upper and lower electrodes.
[f] Electrode diameters are based on the following: ISO Standards 10, 13, 16, 19, and 25 mm; RWMA Standards 0.38, 0.48 (0.50), 0.63, 0.75, 0.88, and 1.00 in.
[g] For DC welding equipment, lower current settings may be appropriate.
[h] Minimum spacing is that spacing for which no special precautions need be taken to compensate for shunted current effect of adjacent welds.

4.1.3.1 Electrodes. Electrodes made from Resistance Welding Manufacturers Alliance (RWMA) Group A, Class 2 copper (see Table 7) are generally recommended for these steels because this group of electrodes maintains relatively high strengths at elevated temperatures. They will have a reasonably long life when correctly used to weld these steels. These electrodes are copper–chromium or copper–chromium–zirconium and exhibit higher strengths and correspondingly reduced electrical conductivities than Class 1 copper electrodes.

4.1.3.2 Net Electrode Force. High-strength (HS) steels, those with minimum tensile strength higher than 500 MPa [72 ksi] typically require higher electrode forces than low-strength, low-carbon steels. The higher forces are necessary to compensate for their higher strengths. Additionally, the bulk resistance of HS steels is greater than that for low-carbon steels, and the increase in electrode force is used to promote proper heat balance. HS steels may require clamping adjacent to the weld area in order to obtain proper joint fit-up. Insulation should be used to prevent current shunting through the clamps. HS steels, because of their higher yield strengths, may experience excessive spring-back after completion of the weld if the adjacent clamping force is not adequate. Excessive spring-back may result in weld fracture. However, electrodes *should not be used as clamping tools* to overcome poor joint fit-up.

4.1.3.3 Hold Time. Hold time is the time that the electrode is in contact with the workpiece after the welding current has been terminated. Hold time allows the electrodes to hold and support the molten nugget. Further, hold time helps the weld solidification process by allowing the water-cooled electrodes to remove heat from the weld, solidifying weld nugget. Typical hold time to solidify the weld nugget varies from 5 to 15 cycles for low-carbon and low-alloy steels. Some steels may show interfacial weld fractures in peel tests when welded with long hold times (typically longer than 30 cycles), whereas when welded with short hold times (typically 5–10 cycles) show button pull fractures. This phenomenon is known as "hold time sensitivity". However, with high strength steels (tensile strength higher than 500 MPa [72 ksi]), especially at heavier gauges, interfacial fractures may be the normal mode of fracture even when short hold times are used. Therefore, hold time sensitivity is not a relevant phenomenon for these steels. To check for hold time sensitivity of a steel grade, make welds on peel test samples using short (5–10 cycles) and long hold times (30 or more cycles). Then

Table 7
Electrode Materials for Resistance Welding

RWMA Class	Group A—Copper Base Alloys	UNS Number
Class 1	Zirconium copper	C15000
Class 2	Chromium copper	C18200
	Chromium zirconium copper	C18150
Class 3	Cobalt beryllium copper[a]	C17500
	Nickel beryllium copper[a]	C17510
	Nickel silicon chromium copper	C18000
Class 4	Beryllium copper[a]	C17200
Class 5	Aluminum bronze	C95300
	Group B – Refractory Metal or Refractory Metal Composites	
Class 10	Copper tungsten (45% Cu/55% W)	C74450
Class 11	Copper tungsten (25% Cu/75% W)	C74400 C74350
Class 12	Copper tungsten (20% Cu/80% W)	
Class 13	Tungsten	C74300
Class 14	Molybdenum	C42300
	Group C – Specialty Materials	
Class 20	Dispersion strengthened copper	C15760

[a] Beryllium (Be). The use of Beryllium may be hazardous; thus requiring special handling and their use must conform with occupational safety and health standards.

peel the welds and examine the weld area. If the weld exhibits interfacial fracture, or results in a partial button, the material is considered hold time sensitive.

4.1.3.4 Temper Time. Medium-carbon and some HS steels may require postweld heating. This may be obtained by applying a separate tempering current in the weld schedule. The weld should be cooled to a temperature below the critical temperature for martensite formation before the application of the tempering current. The tempering current should not remelt the weld nugget nor reheat the weld above the austenitizing temperature. Note the use of temper current may degrade the welding electrodes and shorten the electrode life. Therefore, it is recommended electrode life tests be conducted to assess the effect of tempering current on the electrode life. Further, the use of postweld tempering may add to the total processing time of parts in a production environment and may not be feasible.

4.1.3.5 Weld Current. Compared with low-strength, low-carbon steels, HS steels have higher bulk resistivities. For this reason, HS steels may require lower current levels than low-carbon steels of similar thickness in order to produce similar weld nugget diameters.

4.2 Coated Carbon and Low-Alloy Steels

4.2.1 Introduction. Metallic or nonmetallic coatings are applied to sheet steels primarily to improve the corrosion resistance of the steel during service. These coatings require certain considerations. For example, the presence of coatings alters the contact resistance at the electrode-to-workpiece interface and faying surfaces. Coated steels generally require increased current, which may result in increased heating of the electrode. Coatings may cause rapid erosion of electrodes by wear, or by alloying with the electrode material. Electrode sticking due to this alloying can result in pitting of the electrode tip and rapid electrode face erosion. In addition, some alloying of the coating with the base metal may occur, which may alter corrosion protection.

Coated steel may give off fumes while being welded. Care should be taken to ensure proper ventilation to remove these fumes from the welding area.

4.2.2 Types of Coating. The following is a list of various types of coatings used on steels along with some comments:

(1) Zinc–Base. These coatings are normally applied either by hot-dipping or by electrolytic deposition.

- (a) Zinc (commonly referred to as galvanized or electro-galvanized)
- (b) Zinc–aluminum (Zn + 5 percent Al)
- (c) Zinc–nickel
- (d) Chromium + chromium-oxide + zinc
- (e) Zinc–iron (commonly referred to as galvannealed or electro-galvannealed)

(2) Aluminum–Base

- (a) Type 1 aluminum (Al with 5–10 percent Si)
- (b) Type 2 aluminum (pure Al)
- (c) Aluminum–zinc (45 percent Zn + 1.5 percent Si)

(3) Lead–tin alloy (Terne coating)

(4) Tin

(5) Zinc-based primer. For single-side coated steel, the higher electrical resistance caused by the zinc-based primer can lead to short electrode life if the coating is facing the electrode. However, the bare steel at the faying interface improves weldability.

(6) Organic composite. These coatings are applied to steels that have been metallically coated, and have undergone a chromate treatment. An organic or organic-silicate coating is the third and final layer. The composite coatings are typically applied to one side of the steel sheet. Paint, vinyl, or other nonconducting organic coatings may prevent direct resistance welding. The composite coatings with high electrical resistance can cause increased electrode wear when the coating is facing the electrode.

(7) Metallic plating. Steels may be plated with chromium, nickel, tin, zinc, copper, or cadmium. Chromium and nickel platings have welding schedules similar to an equivalent gauge of uncoated steel; however, an adjustment in weld-

ing current may be required. When welding plated steels, care must be taken to provide adequate ventilation and remove any fumes which may form while welding. For example, cadmium-plated steels, or steels having cadmium-bearing coatings, form toxic cadmium fumes during welding. Generally, welding alters the plating in the area of the weld.

(8) Phosphate. Phosphate coatings have high electrical resistance and thicker phosphate coated steels are difficult to weld.

A pulsation or upslope of welding current may be required to break through some of the coatings discussed above because of their high electrical resistance. Coated electrodes, or electrodes covered with a protective and removable metal layer, can provide longer electrode life when welding coated metals.

4.2.3 Surface Conditions. Prior to welding, the workpiece surface should be free of contaminants which may adversely affect weld quality.

Zinc Coated steel coils are generally shipped in oiled condition where the coils can be safely stored for extended periods of time without any deterioration of the corrosion behavior of the steels. Steels can oxidize to form zinc-hydroxide or white rust. White rust is a wet storage stain, and can best be prevented by storing the coated steels in dry areas. White rust is a nonconducting layer which can create difficulty with the resistance welding of coated steel. Removal of the white rust by wire brushing or chemical cleaning prior to welding is highly recommended.

Aluminum-coated steel may require wire brushing or chemical cleaning prior to welding. In some instances, the tenacious aluminum oxide layer should be removed to minimize nugget expulsion and electrode tip pick-up of aluminum.

4.2.4 Welding Parameters. The data shown in Tables 1 through 5 are offered as a guide to develop welding schedules for coated, low-strength low-carbon and HSLA steels. The following subclauses are comments and discussions pertaining to these data. Additional comments and discussions applicable to carbon and low-alloy steels as well as other metals are presented separately in 4.7.

4.2.4.1 Electrodes (See Table 7)

(1) Electrode Material. Industry uses several electrode materials for the resistance welding of coated steels.

The individual application—including size, shape, materials being welded, and weld schedule has dictated different material selections. These electrode materials are selected for the following characteristics and properties:

RWMA Group A, Class 1 materials are a relatively weak electrode material, but they exhibit the highest conductivity. They can conduct the increased currents associated with coated steels and cool the face quicker, which can retard alloying between the coating and the electrode.

RWMA Group A, Class 2 materials are used for welding coated steel because of their higher strength, which better matches the strength of steel than Class 1. These materials have increased resistance to annealing (softening) and thus, mushrooming is retarded. Class 2 materials are the most widely used.

RWMA Group A, Class 3 and 4 materials are used for welding coated steel when high weld forces are necessary. These materials have a high resistance to annealing (softening), thus reducing the effect of mushrooming when compared to Class 2 materials. The drawback to these materials is reduced conductivity; therefore selection must be coordinated with the power supply.

RWMA Group C, Class 20 dispersion strengthened copper electrode usage has increased with the introduction of new coatings and expanded use of traditional galvanized coated steels. These electrodes have strength and conductivity properties similar to Class 2 materials. In addition, they exhibit greater resistance to annealing (softening) and are noted for increased resistance to sticking to coated material.

(2) Electrode Shape. There are several standard and nonstandard electrode shapes available (see Figure 2).

Seam-welding electrode configurations are available in wheel form. Wire-wheel seam welding, which uses a continuously-fed wire as an intermediate electrode between the electrode wheel and the workpiece, is also an acceptable configuration.

(3) Electrode Life. Electrode life can be defined as the number of welds that can be made with a pair of electrodes and maintain weld button diameters above a specified minimum value and of an acceptable appearance. Another definition of electrode life is the appearance of the first substandard weld.

Coated steel typically shortens electrode life more than uncoated steel. The coating may alloy with the copper electrode and result in electrode sticking and pitting of the electrode face. Coatings that contain zinc, aluminum, tin, or cadmium can alloy easily with the copper electrodes. Different coatings, their thicknesses, and the consistency of the thickness of a coating, result in different electrode wear characteristics.

4.2.4.2 Net Electrode Force. Coated steels typically require higher electrode forces than uncoated steels. This is especially true for steels with multilayered coatings or primers. When welding AHSS, higher electrode forces are particularly required at shorter weld times, and can help reduce internal porosity and nugget shrinkage.

Coated HS steels typically require higher forces than coated low-strength, low-carbon steels. See 4.1.3.2.

4.2.4.3 Weld Time. Coated steel requires longer weld time than that for uncoated steel. Weld time may need to be increased as the coating thickness increases.

The presence of coatings on the steel surface increases the length the current has to travel and therefore, increases the resistance for a given current. The higher currents required for welding coated steels can lower the electrode life due to increased electrode heating. The welding current working envelope (lobe) for coated steel is narrower than that for uncoated steel.

Cadmium- and tin-coated steels require welding schedules similar to zinc-coated steels, but may require lower currents. Aluminum- and aluminum-alloy coated steels may require higher current compared to zinc-coated and uncoated steels. Aluminum-zinc-coated steels require currents slightly less than for zinc-coated steels. Spot-welding schedules for zinc-based primer and organic composite coated steels are similar to those for metallic-coated steels, but may require lower welding currents.

Series or parallel welding may be difficult for coated steels. Secondary circuit variations make it difficult to control weld quality, due to nonuniform metal conditions and electrode deterioration at the paired weld locations. In addition, series welding relies on the workpiece to conduct weld current from one electrode to the other; which can prove difficult with coated steels with soft coatings with a high conductivity, for example, zinc.

4.2.4.4 Hold Time. Short hold time may be necessary for coated steels in order to reduce electrode sticking. Coated HS steels may require very low hold time. See 4.1.3.3.

4.2.4.5 Temper Time. Temper time may be incorporated into the welding schedule when welding coated HS steels and medium-carbon steels. These steels may require heat treatment after being welded in order to improve the mechanical properties of the weld. After completing the weld, the welding cycle will go through a quench time (sometimes referred to as the cool time), during which no current flows through the workpiece, and the weld is rapidly cooled by the electrodes. The temper time follows the quench time. Tempering is obtained by applying an additional current, the magnitude of which is a fractional value of the original welding current.

The weld should be cooled to a temperature below the critical temperature for martensite formation before application of the tempering current. The tempering current must not remelt the weld nugget, and should not reheat the weld above the austenitizing temperature. Proper set-up for any particular alloy may require considerable adjustment of the quench and temper times, and of the temper current level for best results. As mentioned earlier in 4.1.3.4, the use of temper time may increase the total processing time for parts and also adversely affect the electrode life.

4.2.4.6 Welding Current. Coated steels typically require higher currents than uncoated steels. Increased coating weights may require higher welding current or longer weld time, or both.

HS steels have higher bulk electrical resistivities than low-carbon steels. For this reason, coated HS steels may require lower current levels than coated low-carbon steels of similar thickness to produce similar nugget diameters.

4.2.5 Seam Welding. Seam-welding coated steel requires more control over welding conditions than spot welding. Proper control is necessary at higher speeds since the weld is not contained by the electrode force. Excessive welding speeds and high currents can cause cracking in resistance seam welds.

4.3 Aluminum Alloys

4.3.1 Introduction. The resistance welding of aluminum and aluminum alloys is considerably different from other metals due to the physical and chemical properties described below:

(1) Aluminum and its alloys have substantially higher thermal and electrical conductivities than most materials that are resistance welded. This necessitates the use of higher welding current.

(2) Aluminum has a narrow plastic temperature range. This and its high thermal expansion and contraction may require the use of shorter weld times and special weld force application sequences utilizing rapid follow up, along with low inertia equipment for some applications.

(3) Aluminum readily oxidizes on the surface, producing a high and inconsistent contact resistance. Removal of this oxide requires a chemical or mechanical cleaning process.

(4) Aluminum alloys fall into two general classifications: heat treatable and nonheat treatable. The nonheat treatable alloys may be hardened by cold working to some degree. Table 8 shows the alloy designation groups and major alloying elements. An indication is also given as to whether the alloy designation is considered heat treatable. In general, the high-strength heat treatable alloys (2000, 6000, and 7000 series) have a greater tendency toward weld cracking and porosity than other alloys.

(5) The temper of an aluminum alloy influences its weldability, with the soft tempers being generally more difficult to weld. Deformation under the electrode force causes variations in current and force distribution that can result in inconsistent weld strength.

(6) A heat treatable aluminum alloy of a given temper may have a wide range of bulk electrical conductivity.

This can cause inconsistent welds with inadequate size or penetration. Heat treating conditions should be closely monitored to control this condition.

The weldability of various alloys and tempers in similar and dissimilar combinations is shown in Tables 8 and 9.

4.3.2 Surface Condition. The high surface resistance of aluminum and its alloys as received from the mill is due to the presence of a film of aluminum oxide and other contaminants from the rolling or extruding process. This surface resistance is nonuniform and, in most cases, prevents consistent weld strength and quality. The preweld cleaning should yield a clean surface of uniform electrical resistance. This surface will reduce variations in welding heat at the joint interface, and improve weld consistency. Twenty-four hours after cleaning, the rate of surface oxide growth grows dramatically, allowing for more stable and consistent welding parameters to be utilized in production. The acceptable holding period, or elapsed time between cleaning and welding, may vary from a few hours to 48 hours, or more, depending on the cleaning process used, cleanliness of the shop, the particular alloy, and other factors. Aluminum may be spot welded without mechanical or chemical cleaning, discussed below. Either bare copper electrodes or coated electrodes may be used.

The surface may be cleaned, either chemically or mechanically, as described below:

(1) Chemical Cleaning. The chemical solution cleaning process is desirable for large production volumes. Several steps are involved in the cleaning. A nonetching alkaline cleaning solution should be used first to remove heavy oils or grease, followed by a water rinse. Use precaution when handling alkaline (caustic) solutions. They can cause chemical burns and violent chemical reactions can result when mixed with acids. Before use, read and understand the manufacturer's instructions, Safety Data Sheets (SDSs), and your employer's safety practices. The next step is immersion in a solution to remove the oxide film followed by a water rinse. The final step should be drying with forced air with or without heat.

Table 8
Basic Aluminum Alloy Groups

Major Alloying Elements	Designation[a]
99.0% Min. Aluminum	1xxx
Copper	2xxx[b]
Manganese	3xxx
Silicon	4xxx
Magnesium	5xxx
Magnesium and Silicon	6xxx[b]
Zinc	7xxx[b]

[a] Aluminum association designations.
[b] Heat-treatable alloys.

Table 9
Resistance Weldability Chart for Commonly Used Combinations of Aluminum Alloys (Based on Equal Thickness)

Alloy (with temper designations)	1100 –0 3003 –0	1100 –H12 –H14 –H16 –H18 3003 –H12 –H14 –H16 –H18	3004	3004 – – – –	5050 –0	5050 –H32 –H34 –H36 –H38	5052 –0	5052 –H32 –H34 –H36 –H38	5356 –0	5356 –H32 –H34 –H36 –H38	2014 –T4 –T6 –T3 –T4	2014 Clad –T4 –T6 Hard –T3 –T4	2024 –T3 –T4	2024 Clad –T3 –T4	6061 –T4 –T6	6063 –T5 –T6	7075 –T6	7075 Clad –T6
1100– 3003–	A4 B1 C1	A3 B1 C1	A4 B1 C1	A3 B1 C1	A4 B1 C1	A3 B1 C1	A4 B2 C1	A3 B2 C1						A4 B2 C1	A3 B2 C1	A3 B2 C1		
1100-H12-H14-H16- 3003-H12-H14-H16-	A3 B1 C1	A1 B1 C1	A3 B2 C1	A1 B1 C1	A3 B2 C1	A1 B2 C1	A3 B2 C1	A1 B2 C1						A4 B2 C1	A1 B2 C1	A1 B1 C1		
3004–	A4 B1 C1	A3 B2 C1	A4 B1 C1	A3 B1 C1	A4 B2 C1	A3 B2 C1	A4 B2 C1	A3 B2 C1		A3 B2 C1					A3 B2 C1	A3 B2 C1		
3004-H32-H34-H36-	A3 B1 C1	A1 B1 C1	A3 B1 C1	A1 B1 C1	A3 B2 C1	A1 B2 C1	A4 B2 C1	A1 B2 C1		A1 B2 C1					A1 B2 C1	A1 B2 C1		
5050–	A4 B1 C1	A3 B1 C1	A4 B2 C1	A3 B2 C1	A4 B2 C1	A3 B2 C1	A4 B2 C1	A3 B2 C1							A3 B2 C1	A3 B2 C1		
5050-H32-H34-H36-	A3 B1 C1	A1 B2 C1	A3 B2 C1	A1 B2 C1	A3 B2 C1	A1 B2 C1	A3 B2 C1	A1 B2 C1		A1 B2 C1					A1 B2 C1	A1 B2 C1		
5052–	A4 B2 C1	A3 B2 C1	A4 B2 C1	A4 B2 C1	A4 B2 C1	A3 B2 C1	A4 B2 C1	A3 B2 C1							A3 B2 C1	A3 B2 C1		
5052-H32-H34-H36-	A3 B2 C1	A1 B2 C1	A3 B2 C1	A1 B2 C1	A3 B2 C1	A1 B2 C1	A3 B2 C1	A1 B2 C1		A1 B2 C1	A2 B2 C2	A2 B2 C1	A2 B2 C2	A2 B2 C1	A1 B2 C1	A1 B2 C1	A2 B2 C2	A2 B2 C1
5356–									A4 B1 C1	A3 B1 C1					A3 B2 C1	A3 B2 C1		

Table 9 (continued)
Resistance Weldability Chart for Commonly Used Combinations of Aluminum Alloys (Based on Equal Thickness)

5356-H32-H34-H36-H38			A3 B2 C1	A1 B2 C1		A1 B2 C1		A1 B2 C1	A3 B1 C1	A1 B1 C1					A1 B2 C1	A1 B2 C1		
2014-T4-T6		–H18						A2 B2 C2			A2 B2 C2	A2 B2 C1	A2 B2 C2	A2 B2 C2	A2 B2 C2	A2 B2 C2	A2 B2 C2	A2 B2 C2
Alclad 2014-T4-T6 Hardclad-T3								A2 B2 C1			A2 B2 C1	A2 B2 C1	A2 B2 C2	A2 B2 C1	A2 B2 C1	A2 B2 C1	A2 B2 C2	A2 B2 C1
2024-T3-T4								A2 B2 C2			A2 B2 C2	A2 B2 C2	A2 B2 C2	A2 B2 C2	A2 B2 C2	A2 B2 C2	A2 B2 C2	A2 B2 C2
Alclad 2024-T3-T4	A4 B2 C1	A4 B2 C1						A2 B2 C1			A2 B2 C2	A2 B2 C1	A2 B2 C2	A2 B2 C1	A2 B2 C1	A2 B2 C1	A2 B2 C2	A2 B2 C1
6061-T4-T6	A3 B2 C1	A1 B2 C1	A3 B2 C1	A1 B2 C1	A3 B2 C1	A1 B2 C1	A3 B2 C1	A1 B2 C1	A3 B2 C1	A1 B2 C1	A2 B2 C2	A2 B2 C1	A2 B2 C2	A2 B2 C1	A2 B2 C1	A2 B2 C1	A2 B2 C2	A2 B2 C1
6063-T5-T6	A3 B2 C1	A1 B1 C1	A3 B2 C1	A1 B2 C1	A3 B2 C1	A1 B2 C1	A3 B2 C1	A1 B2 C1	A3 B2 C1	A1 B2 C1	A2 B2 C2	A2 B2 C1	A2 B2 C2	A2 B2 C1	A1 B2 C1	A1 B2 C1	A2 B2 C2	A2 B2 C1
7075-T6								A2 B2 C2			A2 B2 C2	A2 B2 C1	A2 B2 C2	A2 B2 C1	A2 B2 C2	A2 B2 C2	A2 B2 C2	A2 B2 C2
Alclad 7075-T6								A2 B2 C1			A2 B2 C2	A2 B2 C1	A2 B2 C2	A2 B2 C1	A2 B2 C1	A2 B2 C1	A2 B2 C2	A2 B2 C1

Notes:
A. Ease of welding
- A1. Good welds can be made over a wide range of machine settings.
- A2. Makes good welds but special practices required and can be welded only over narrower range of machine settings.
- A3. Can be welded but material too soft to obtain consistent weld strength.
- A4. Difficult to weld—not recommended.

B. Precleaning
- B1. Easy to clean or in some cases needs no cleaning.
- B2. Chemical or mechanical precleaning necessary to make sound and consistent welds.

C. Resistance to corrosion
- C1. Corrosion resistance of weld zone equal to parent metal.
- C2. Corrosion resistance of weld zone not as good as parent metal.

D. Consultation with the manufacturer is suggested for alloy combustions not acted in the table because of insufficient data.

The chemical solutions should be maintained at the proper strength to ensure satisfactory surface preparation. The concentration may be determined by titration, and additions of chemicals to the solutions should be made when necessary. The cleaning effectiveness of the solutions can be adversely affected by contamination. Contaminated solutions should be drained and replaced.

The principal advantages of chemical cleaning are low unit cost, large production capacity, and uniform results. The principal disadvantages are high capital investment, exacting controls, and the cost and difficulty of waste disposal.

Rinsing is required after each step; otherwise chemicals from the previous operation will be carried into the next bath. Spraying, mechanical agitation, or preferably ultrasonic vibration will reduce the treatment time and at the same time improve the consistency of the results. The quality of the rinsing water is also of importance. Industrial water may contain chemicals that react with the sheet surface and again contaminate it.

NOTE: In the case of alloys containing, e.g., silicon, zinc, and copper, a dark layer may form on the sheet surface during the etching process. This must be removed in a deoxiding bath containing 10% nitric acid.

Drying with heated air may pose a problem because the growth of aluminum oxide increases exponentially with the temperature.

(2) Mechanical Cleaning. The use of mechanical cleaning is generally restricted to small production quantities or isolated spots on large pieces where it is not necessary or economical to clean the entire piece. Mechanical cleaning is recommended when lap joints are present that can entrap chemical solutions.

A precleaner, such as a vapor degreaser or alkaline solution is usually necessary to remove foreign substances prior to mechanical cleaning. The surface to be cleaned may be abraded by a stainless steel wire wheel, abrasive cloth, or abrasive impregnated nylon wheel. Wire brush bristles should not exceed 0.1 mm [0.005 in] diameter and abrasive wheels or paper should not be coarser than 240 grit or the surface can become too coarse. Residual particles from the abrading process must be removed prior to welding.

The principal advantages of mechanical cleaning are low capital investment and the ease of cleaning localized areas. The principal disadvantages are high unit cost, because this process is generally a hand operation, and the difficulty of assuring uniform cleaning. Automated equipment able to clean large sheets can eliminate some of these disadvantages.

4.3.3 Welding Parameters. The data shown in Tables 9 through 14 are offered as a guide to developing spot-welding schedules for aluminum and its alloys. With the number of variables involved, it is impractical to specify welding parameters for every condition or combination. The parameters presented are for the most commonly welded alloys and thicknesses. Although no seam-welding data are given, seam-welding parameters can be developed. Some of these spot-welding data can be used in developing the seam-welding schedules because of the similarity of the two processes. Higher currents are generally needed in seam welding to overcome the effect of current shunting through previously formed welds. Projection welding of aluminum and its alloys is not recommended because of their narrow plastic temperature ranges.

The following subclauses are comments and discussions pertaining to the welding schedule data in these tables. Additional comments and discussions applicable to aluminum alloys as well as other metals are presented separately in 4.7.

4.3.3.1 Electrodes. RWMA Group A, Class 1 copper electrodes are the most commonly used for resistance welding aluminum and its alloys. RWMA Class 1 copper electrodes have high electrical and thermal conductivities but are not heat treatable. If higher strength electrodes are needed, RWMA Group A, Class 2 copper electrodes may be used. The lower electrical and thermal conductivities of the Class 2 copper alloy makes it less suitable for welding aluminum except in those cases requiring higher electrode strength or in combination with Class 1 electrodes to control weld penetration in dissimilar metal or thickness combinations. When welding with DC, consideration should be given to the fact the cathode electrode will erode faster than the anode. Electrodes with specialized geometries or coatings have been developed to address issues presented during the welding of aluminum.

4.3.3.2 Net Electrode Force. Generally, the lower strength, nonheat treatable aluminum alloys require less electrode force than do the higher strength heat treatable alloys.

Aluminum has higher shrinkage upon solidification than steel. Use of a low-inertia, low-friction welding head assures rapid follow up to reduce weld defects. In seam welding, higher quality welds are produced with indexing electrode wheels rather than with wheels turning during welding.

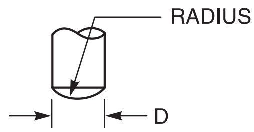
Table 10
Recommended Spot-Weld Spacing, Edge Distance, Overlap, and Distance between Rows of Welds for Aluminum and Its Alloys

		mm [in]											
Sheet Thickness[a]	mm[b] [in]	0.41 [0.016]	0.51 [0.020]	0.64 [0.025]	0.81 [0.032]	1.02 [0.040]	1.27 [0.050]	1.60 [0.063]	1.80 [0.071]	2.03 [0.080]	2.29 [0.090]	2.54 [0.100]	3.18 [0.125]
Minimum Weld[c] Spacing	MIL[d]	9.5[0.37]	9.5[0.37]	9.5[0.37]	12.7[0.50]	12.7[0.50]	15.9[0.63]	15.9[0.63]	19.0[0.75]	19.0[0.75]	22.2[0.87]	25.4[1.00]	38.1[1.25]
	COMM[e]	12.7[0.50]	12.7[0.50]	15.9[0.63]	15.9[0.63]	19.0[0.75]	19.0[0.75]	25.4[1.00]	28.6[1.13]	28.6[1.13]	31.8[1.25]	34.9[1.37]	38.1[1.25]
Minimum Distance[f] Between Rows of Welds	MIL[d]	6.4[0.25]	6.4[0.25]	7.9[0.31]	7.9[0.31]	9.5[0.37]	9.5[0.37]	9.5[0.37]	11.1[0.44]	12.7[0.50]	12.7[0.50]	12.7[0.50]	15.9[0.63]
	COMM[e]	6.4[0.25]	6.4[0.25]	6.4[0.25]	9.5[0.37]	12.7[0.50]	15.9[0.63]	22.2[0.87]	25.4[1.00]	25.4[1.00]	28.6[1.13]	34.9[1.37]	34.9[1.37]
Minimum[g] Edge Distance	MIL[d]	4.8[0.19]	4.8[0.19]	5.6[0.22]	6.4[0.25]	6.4[0.25]	7.9[0.31]	9.5[0.37]	9.5[0.37]	9.5[0.37]	11.1[0.44]	11.1[0.44]	12.7[0.50]
	COMM[e]	4.8[0.19]	4.8[0.19]	5.6[0.22]	6.4[0.25]	6.4[0.25]	7.9[0.31]	7.9[0.31]	9.5[0.37]	9.5[0.37]	11.1[0.44]	11.1[0.44]	12.7[0.50]
Minimum Contacting Overlap	MIL[d]	9.5[0.37]	9.5[0.37]	11.1[0.44]	12.7[0.50]	14.3[0.56]	15.9[0.63]	19.0[0.75]	20.6[0.81]	22.2[0.87]	23.8[0.94]	25.4[1.00]	28.6[1.13]
	COMM[e]	9.5[0.37]	9.5[0.37]	11.1[0.44]	12.7[0.50]	12.7[0.50]	15.9[0.63]	15.9[0.63]	19.0[0.75]	19.0[0.75]	19.0[0.75]	22.2[0.87]	25.4[1.00]

[a] For combinations of unequal thickness, use the thickness one lower than the heaviest to be welded as the thickness controlling dimensions indicated.
[b] All dimensions are in mm [in].
[c] Minimum weld spacing is that for which no special precautions need be taken to compensate for shunted current effects of adjacent welds. It is measured from weld center-to-center.
[d] MIL = military requirements.
[e] COMM = commercial requirements.
[f] Distance between rows of welds is measured from weld center to weld center.
[g] Edge distance is measured from weld center to edge of sheet.

Table 11
Spot-Welding Parameters for Aluminum Alloys on Standard Single-Phase A-C Type Equipment[a, b, c]

Electrode Diameter and Shape[d]



Sheet Thickness mm [in]	D[e] mm [in]	Radius mm [m] Top Electrode	Radius mm [m] Bottom Electrode	Net Electrode Force [Weld] kN [lb]	Welding Current Approx. Amps	Welding[b] Time Approx. Cycles	Welding[b] Time Approx. ms
0.41 [0.016]	16 [0.63]	1	Flat	1.42 [320]	15 000	4	66
0.51 [0.020]	16 [0.63]	1	Flat	1.51 [340]	18 000	5	83
0.64 [0.025]	16 [0.63]	2	Flat	1.73 [390]	21 800	6	100
0.81 [0.032]	16 [0.63]	2	Flat	2.22 [500]	26 000	7	116
1.02 [0.040]	16 [0.63]	3	Flat	2.67 [600]	30 700	8	133
1.27 [0.050]	16 [0.63]	3	Flat	2.96 [660]	33 000	8	133
1.60 [0.063]	16 [0.63]	3	Flat	3.34 [750]	35 800	10	166
1.80 [0.071]	16 [0.63]	4	4	3.56 [800]	35 000	10	166
2.03 [0.080]	22 [0.88]	4	4	3.83 [860]	41 800	10	166
2.29 [0.090]	22 [0.88]	6	6	4.23 [950]	46 000	12	200
2.54 [0.100]	22 [0.88]	6	6	4.67 [1050]	56 000	15	250
3.18 [0.125]	22 [0.88]	6	6	5.78 [1300]	76 000	15	250

Note: The parameters shown represent a starting point from which a weld schedule can be established.
[a] Types of aluminum alloy: 1100-H12-H18, 3003-H1211-H18, 3004-H32-H38, 5052-H32-H38, 5050-H32-H38, 5356-H32-H38, 6061-T4-T6, 6063-T5-T6.
[b] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz equipment, multiply the weld times shown in cycles by 0.83, then round down to the nearest whole number.
[c] For DC welding equipment, lower current settings may be appropriate.
[d] Electrode material: RWMA Class 1.
[e] Electrode diameters are based on the following: ISO Standards 13, 16, 19, and 22 mm; RWMA Standards 0.48 (0.50), 0.63, 0.75, 0.88, and 1.00 in.

The variable force cycle, in which the weld is made at a low force, followed by application of a carefully timed higher force, is used to improve the weld soundness of some aluminum alloys during the solidification of the weld. The timing of application of forging force is very critical. If applied too late, the weld will have already solidified, and no improvement will result. If applied too soon, the sudden increase in contact area will lower the resistance, possibly making the weld current insufficient to allow a full size and strength weld to develop. The actual timing of the forging force may be determined by measuring the weld force and current as a function of time.

4.3.3.3 Weld Time. Short weld times are desirable when welding aluminum because of its narrow plastic temperature range. Thicker sheets require more weld time than thinner sheets. Since short weld times are desired, the rate of heat rise should be steep. However, excessively high rates of heat rise will result in porous, cracked welds, or weld expulsion.

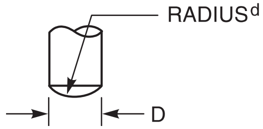
4.3.3.4 Weld Current. Higher currents are generally required for welding aluminum than steel and some other metals because of its higher electrical and thermal conductivities and low surface electrical resistance after cleaning. Current sloping is frequently used on aluminum to control the cooling rate to reduce weld defects.

4.4 Stainless Steels, Nickel, Nickel-Base, and Cobalt-Base Alloys

4.4.1 Introduction. Most of these metals can be readily resistance welded. As an exception the cast precipitation-hardenable, nickel-base alloys with low ductility are among those that are normally difficult to resistance weld without cracking.

Table 12
Spot-Welding Parameters for Aluminum Alloys on Single-Phase A-C Slope Control Type Machines[a]

Electrode Diameter and Shape[b,c]



Alloy	Sheet Thickness mm [in]	Electrode Diameter and Shape[b,c]: D mm [in]	Electrode Diameter and Shape[b,c]: Radius mm [in]	Net Electrode Force, kN [lb]: Weld	Net Electrode Force, kN [lb]: Forge	Time: Up Slope Cycles[e]	Time: Up Slope ms	Time: Weld Heat Cycles[e]	Time: Weld Heat ms	Time: Down Slope Cycles[e]	Time: Down Slope ms	Time: Weld Time Cycles[e]	Time: Weld Time ms	Weld Current Approx Amps × 1000: Initial	Weld Current Approx Amps × 1000: Weld	Weld Current Approx Amps × 1000: Final Post heat
2024 and 7075	0.64 [0.025]	16 [0.63]	76 [3.0]	2.2 [500]	4.9 [1100]	2	33	4	66	4	66	8	133	7.0	22.0	11.0
	0.81 [0.032]	16 [0.63]	76 [3.0]	2.7 [600]	5.7 [1280]	2	33	5	83	4	66	9	150	8.0	24.0	13.0
	1.02 [0.040]	16 [0.63]	76 [3.0]	3.1 [700]	6.2 [1400]	2	33	6	100	5	83	11	183	9.0	27.0	15.0
	1.27 [0.050]	16 [0.63]	76 [3.0]	3.6 [800]	7.6 [1700]	3	50	8	133	5	83	13	216	10.0	30.0	17.0
	1.63 [0.063]	16 [0.63]	152 [6.0]	4.2 [950]	8.9 [2000]	3	50	10	166	6	100	16	266	11.0	34.0	20.0
	1.80 [0.071]	16 [0.63]	152 [6.0]	4.9 [1100]	9.8 [2200]	3	50	12	200	6	100	18	300	12.0	37.0	22.0
	2.03 [0.080]	22 [0.88]	152 [6.0]	5.3 [1200]	11.1 [2500]	3	50	13	216	7	116	20	333	13.0	40.0	25.0
	2.29 [0.090]	22 [0.88]	152 [6.0]	6.2 [1400]	13.3 [3000]	4	66	15	250	8	133	23	383	14.0	43.0	28.0
	2.54 [0.100]	22 [0.88]	152 [6.0]	7.6 [1700]	16.5 [3700]	4	66	16	266	9	150	25	416	15.0	47.0	31.0
	3.18 [0.125]	22 [0.88]	152 [6.0]	8.9 [2000]	20.0 [4500]	5	83	20	333	10	166	30	500	16.5	55.0	33.0
5052 and 6061	0.64 [0.025]	16 [0.63]	76 [3.0]	2.0 [450]	4.4 [1000]	2	33	4	66	4	66	8	133	6.5	21.0	11.0
	0.81 [0.032]	16 [0.63]	76 [3.0]	2.4 [550]	5.1 [1150]	2	33	5	83	4	66	9	150	7.5	23.0	13.0
	1.02 [0.040]	16 [0.63]	76 [3.0]	2.7 [600]	5.8 [1300]	2	33	6	100	5	83	11	183	8.0	25.0	14.0
	1.27 [0.050]	16 [0.63]	76 [3.0]	3.1 [700]	6.7 [1500]	3	50	8	133	5	83	13	216	9.0	28.0	16.0
	1.63 [0.63]	16 [0.63]	152 [6.0]	3.7 [830]	7.8 [1750]	3	50	10	166	6	100	16	266	10.0	31.0	18.0
	1.80 [0.071]	16 [0.63]	152 [6.0]	4.0 [900]	8.9 [2000]	3	50	12	200	6	100	18	300	11.0	33.0	20.0
	2.03 [0.080]	22 [0.88]	152 [6.0]	4.4 [1000]	9.8 [2200]	3	50	13	216	7	116	20	333	12.0	36.0	22.0
	2.29 [0.090]	22 [0.88]	152 [6.0]	5.3 [1200]	10.7 [2400]	4	66	15	250	8	133	23	383	13.0	40.0	23.0
	2.54 [0.100]	22 [0.88]	152 [6.0]	6.2 [1400]	12.9 [2900]	4	66	16	266	9	150	25	416	14.0	44.0	28.0
	3.18 [0.125]	22 [0.88]	152 [6.0]	8.9 [2000]	17.8 [4000]	5	83	20	333	10	166	30	500	18.0	53.0	37.0

Note: The parameters shown represent a starting point from which a weld schedule can be established.
[a] For DC welding equipment, lower current settings may be appropriate.
[b] Electrode material RWMA Class 1.
[c] Electrode diameters are based on the following: ISO Standards 13, 16,19, and 25 mm; RWMA Standards 0.48(0.50), 0.63, 0.75, 0.88, and 1.00 in.
[d] The top and bottom electrodes should have the same tip radius, or one has a radius tip and the other a flat tip.
[e] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz equipment, multiply the weld times shown in cycles by 0.83, then round down to the nearest whole number.

An interesting phenomenon known as coring has been observed in the heat-affected zone of resistance welds of nickel-base alloys. The area may appear to resemble a crack depending on the etching procedure and magnification. However, when it is properly etched and at enough magnification, the area can be seen completely filled with dendritic material as shown in Figure 1. Based on its dendritic structure, the area appears caused by either incipient melting or a crack which has been backfilled by the molten weld metal. Coring can be reduced in some welds by external water cooling during welding.

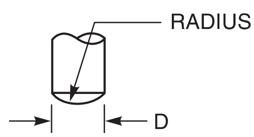
Many of the alloys discussed in this clause are precipitation-hardenable. For these alloys, a postweld heat treatment is usually needed to produce a hardness in the weld region similar to that of the alloy in the fully heat-treated condition.

4.4.2 Surface Condition. The surfaces to be welded should be clean and free of contaminants that can cause inconsistent welds. In addition, some contaminants might contain a low-melting-point element such as sulfur or lead that can cause hot-cracking in the welds. Machined surfaces and mill descaled rolled-sheet surfaces may be welded after solvent or vapor degreasing. Some solvents are toxic and breathing the fumes can cause dizziness. Other solvents are flammable and require good ventilation; therefore, proper precautions should be taken.

4.4.3 Weld Parameters. The data shown in Tables 15 through 32 are offered as a guide to develop welding schedules for stainless steels, nickel, nickel-base, and cobalt-base alloys. The following subclauses are comments and discussions pertaining to these tables. Additional comments and discussions applicable to the above metals are presented separately in 4.7.

Table 13
Spot-Welding Parameters for Aluminum Alloys on Three-Phase Rectifier-Type Equipment[a]

Electrode Diameter and Shape[b,c,d]



Sheet Thickness mm [in]	D mm [in]	Radius mm [in]	Net Electrode Force kN [lb][e] Weld	Net Electrode Force kN [lb][e] Forge	Welding Current[e] [Approx.] Amps Weld	Welding Current[e] [Approx.] Amps Post Heat	Welding Time[f] [Approx] Weld Cycles[c]	Welding Time[f] [Approx] Weld ms	Welding Time[f] [Approx] Post Heat Cycles[c]	Welding Time[f] [Approx] Post Heat ms
0.41 [0.016]	16 [0.63]	76 [3.0]	2.0 [450]	4.4 [980]	19.0	None	1	16	None	
0.51 [0.020]	16 [0.63]	76 [3.0]	2.3 [520]	5.1 [1150]	22.0	None	1	16	None	
0.81 [0.032]	16 [0.63]	76 [3.0]	3.0 [670]	6.9 [1550]	28.0	None	2	33	None	
1.02 [0.040]	16 [0.63]	76 [3.0]	3.2 [730]	8.0 [1800]	32.0	None	3	50	None	
1.27 [0.050]	16 [0.63]	203 [8.0]	4.0 [900]	10.0 [2250]	37.0	30.0	4	66	4	66
1.60 [0.063]	16 [0.63]	203 [8.0]	4.9 [1100]	12.9 [2900]	43.0	36.0	5	83	5	83
1.80 [0.071]	16 [0.63]	203 [8.0]	5.3 [1190]	1.44 [3240]	48.0	38.0	6	100	6	100
2.03 [0.080]	22 [0.87]	203 [8.0]	6.5 [1460]	16.9 [3800]	52.0	42.0	7	116	7	116
2.29 [0.090]	22 [0.87]	203 [8.0]	7.6 [1710]	19.1 [4270]	56.0	45.0	8	133	8	133
2.54 [0.100]	22 [0.87]	203 [8.0]	8.5 [1910]	22.2 [4990]	61.0	49.0	9	150	9	150
3.18 [0.125]	22 [0.87]	203 [8.0]	11.1 [2500]	28.9 [6500]	69.0	54.0	10	166	10	166

Note: The parameters shown represent a starting point from which a weld schedule can be established.
[a] For DC welding equipment, lower current settings may be appropriate.
[b] Electrode material: RWMA Class 1.
[c] The top and bottom electrodes should have the same tip radius, or one has a radius tip and the other a flat tip.
[d] Electrode diameters are based on the following: ISO Standards 13, 16,19, and 25 mm; RWMA Standards 0.48(0.50), 0.63, 0.75, 0.88, and 1.00 in.
[e] The force and current values for alloys are 2014-T3, T4, T6, 2024-T3, T4, and 7075-T6. Somewhat lower values may be used for alloys such as 5052 and 6061.
[f] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz equipment, multiply the weld times shown in cycles by 0.83, then round down to the nearest whole number.

Figure 1—Coring in Nickel Alloy 718 (UNS N07718) Resistance Seam Weld, 200X

4.4.3.1 Electrodes. Most of these metals retain their high strength at elevated temperatures. Therefore, electrodes for resistance welding these metals are usually RWMA Group A, Class 2, or 3 copper alloys (see Table 7). These copper alloys are age-hardenable and thus have higher strength than RWMA Group A, Class 1, which are not heat treatable.

4.4.3.2 Net Electrode Force. The mechanical properties of these alloys generally necessitate electrode forces higher than those required to weld the equivalent carbon steel thickness. The principal reason is the amount of force required to deform the part to create a localized spot of contact at the faying surface. When welding these alloys in the annealed condition, the ideal weld force could be lower than that required for welding carbon steel if it is beneficial to increase the contact resistance relative to the higher bulk material resistance.

4.4.3.3 Dissimilar Alloys. When dissimilar alloys of similar thicknesses are welded, penetration of the weld nugget into one alloy may be less than into the other alloy because of differences in melting points and thermal and electrical conductivities. For example, when Type 321 stainless steel is welded to nickel alloy 718, penetration into the stainless steel will be less than that into the nickel alloy 718. Penetration into the stainless steel can be increased by installing an electrode with either a lower thermal conductivity or smaller face area, or both, on the stainless steel side. The lower thermal conductivity or smaller face decreases the heat conducted away from the stainless steel by the electrode. A smaller face area will also concentrate the weld current or heat into a smaller area.

4.5 Copper and Copper Alloys. Copper and copper alloys can be resistance spot welded although copper and some of the copper alloys have very high electrical and thermal conductivities. Electrical and thermal conductivities are among the properties of a metal that can significantly affect its resistance weldability. The data shown in Table 33 may be used as a guide to develop spot-welding schedules for various copper alloys. The following techniques may be used to facilitate resistance spot welding of these metals:

(1) Plate the faying surfaces with a higher electrical resistance metal (e.g., tin or nickel) to compensate for the low electrical resistance of the base metal. This technique, best described as resistance brazing, can greatly improve the effectiveness of the bond. Since the plating (brazing filler metal) will remain in the joint, its acceptability should be evaluated based on the service requirements.

(2) Use electrodes faced with a refractory metal like tungsten or molybdenum (e.g., RWMA Group B, Classes 13, and 14), to reduce alloying and sticking of the electrodes to the workpiece.

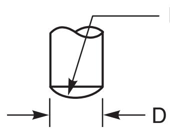
(3) Use a short weld time to minimize metal expulsion and sticking of the electrode to the workpiece.

(4) Because of the narrow plastic range of copper and copper alloys, use machines with a low-inertia welding head. This provides faster follow-up to maintain pressure on the joint to prevent metal expulsion.

4.6 Titanium and Titanium Alloys. Titanium and its alloys can be readily resistance welded. Although they are highly sensitive to embrittlement caused by reaction with air at fusion-welding temperatures, inert-gas shielding is not required because the surrounding base metal protects the molten weld metal from air contamination.

Table 14
Spot-Welding Parameters for Aluminum Alloys on Three-Phase Frequency Converter-Type Equipment (Single Impulse Welds)[a,b]

Electrode Diameter and Shape[c,d]

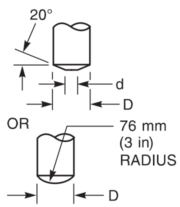


Sheet Thickness mm [in]		Electrode D mm [in]	Electrode Radius mm [in]	Net Electrode Force kN [lb][e] Weld	Net Electrode Force kN [lb][e] Forge	Welding Current[e] [Approx.] Amps × 1000 Weld	Welding Current[e] [Approx.] Amps × 1000 Postheat	Welding Time[a] Weld Cycles	Welding Time[a] Weld ms	Welding Time[a] Postheat Cycles	Welding Time[a] Postheat ms
0.51 [0.020]	COMM[f]	16 [0.63]	76 [3.0]	2.2 [500]	2.2 [500]	26	None	1/2	8	None	None
	MIL[e]	8 [0.31]	254 [10.0]	2.7 [600]	5.3 [1 200]	19	4.0	1	16	2	33
0.64 [0.025]	COMM[f]	16 [0.63]	76 [3.0]	2.2 [500]	5.3 [1 200]	34	8.5	1	16	3	50
	MIL[e]	8 [0.31]	254 [10.0]	2.7 [600]	7.1 [1 600]	25	6.3	1	16	2	33
0.81 [0.032]	COMM[f]	16 [0.63]	102 [4.0]	2.7 [600]	5.8 [1 300]	36	9.0	1	16	4	66
	MIL[e]	8 [0.31]	254 [10.0]	3.1 [700]	8.0 [1 800]	30	7.5	1	16	2	33
1.02 [0.040]	COMM[f]	16 [0.63]	102 [4.0]	3.1 [700]	6.7 [1 500]	42	12.6	1	16	4	66
	MIL[e]	8 [0.31]	254 [10.0]	3.6 [800]	8.9 [2 000]	40	12.0	2	33	4	66
1.27 [0.050]	COMM[f]	16 [0.63]	102 [4.0]	3.6 [800]	8.0 [1 800]	46	13.8	1	16	5	83
	MIL[e]	13 [0.50]	254 [10.0]	4.0 [900]	10.2 [2 290]	43	12.9	2	33	4	66
1.60 [0.063]	COMM[f]	16 [0.63]	152 [6.0]	4.4 [1000]	8.9 [2 000]	54	18.9	2	33	5	83
	MIL[e]	13 [0.50]	254 [10.0]	5.8 [1300]	13.3 [2 990]	51	17.9	3	50	6	100
1.80 [0.071]	COMM[f]	16 [0.63]	152 [6.0]	5.3 [1200]	11.1 [2 500]	61	21.4	2	33	6	100
	MIL[e]	16 [0.63]	254 [10.0]	7.1 [1600]	16.0 [3 600]	57	20.0	3	50	6	100
2.03 [0.080]	COMM[f]	22 [0.87]	152 [6.0]	6.2 [1400]	12.5 [2 810]	65	22.8	3	50	6	100
	MIL[e]	16 [0.63]	254 [10.0]	8.0 [1800]	18.2 [4 090]	63	22.1	4	66	8	133
2.29 [0.090]	COMM[f]	22 [0.87]	152 [6.0]	7.1 [1600]	14.2 [3 190]	75	30.0	3	50	8	133
	MIL[e]	16 [0.63]	254 [10.0]	10.7 [2400]	23.6 [5 310]	73	29.2	4	66	8	133
2.54 [0.100]	COMM[f]	22 [0.87]	203 [8.0]	8.9 [2000]	17.8 [4 000]	85	34.0	3	50	8	133
	MIL[e]	22 [0.87]	254 [10.0]	12.5 [2810]	30.2 [6 790]	81	32.4	5	83	10	166
3.18 [0.125]	COMM[f]	22 [0.87]	203 [8.0]	20.0 [4500]	22.2 [4 990]	100	45.0	4	66	10	166
	MIL[e]	22 [0.87]	254 [10.0]	17.8 [4000]	44.5 [10 000]	100	45.0	5	83	10	166

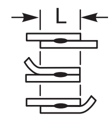
Note: The parameters shown represent a starting point from which a weld schedule can be established.
[a] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz equipment, multiply the weld times shown in cycles by 0.83, then round down to the nearest whole number.
[b] For DC welding equipment, lower current settings may be appropriate.
[c] Electrode material: RWMA Class 1.
[d] Electrode diameters are based on the following: ISO Standards 8, 13, 16, 19, and 22 mm; RWMA Standards 0.31, 0.48 (0.50), 0.63, 0.75, 0.88, and 1.00 in.
[e] MIL = military requirements.
[f] COMM = commercial requirements.

Table 15
Spot-Welding Parameters for Stainless Steels[a]

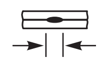
Electrode Diameter and Shape[b,c]



Minimum Contacting Overlap mm [n]



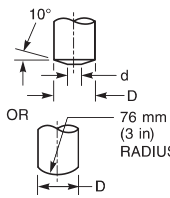
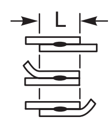
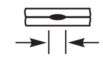
Nugget Diameter mm [in] [Approx.] ω



Sheet Thickness mm [in]	Electrode Diameter and Shape[b,c]: D mm [in] min	Electrode Diameter and Shape[b,c]: d mm [in] max	Net Electrode Force kN [lb]	Weld Time[d] Single Impulse: Cycles	Weld Time[d] Single Impulse: ms	Welding Current [Approx.] Amps[e]: Base Metal Tensile Strength Below 1.03 MPa [150 ksi]	Welding Current [Approx.] Amps[e]: Base Metal Tensile Strength Above 1.03 MPa [150 ksi]	Minimum Contacting Overlap mm [n]	Minimum Weld Spacing [℄ to ℄ it mm [in]	Nugget Diameter mm [in] [Approx.] ω	Minimum Shear Strength KN [1b] Ultimate Tensile Strength of Base Metal: From 480 MPa [70 ksi] Up To 300 MPa [90 ksi]	From 620 MPa [90 ksi] Up To 1.03 MPa [150 ksi]	1.03 MPa [150 ksi] and Higher
0.15 [0.006]	13 [0.50]	3.18 [0.125]	0.8 [180]	2	33	2 000	2 000	7.9 [0.31]	7.9 [0.31]	1.14 [0.045]	0.3 [70]	0.3 [70]	0.4 [90]
0.20 [0.008]	13 [0.50]	3.18 [0.125]	0.9 [200]	3	50	2 000	2 000	7.9 [0.31]	7.9 [0.31]	1.40 [0.055]	0.4 [90]	0.58 [130]	0.64 [146]
0.25 [0.010]	13 [0.50]	3.18 [0.125]	1.0 [220]	3	50	2 000	2 000	7.9 [0.31]	7.9 [0.31]	1.65 [0.065]	0.71 [160]	0.80 [180]	0.93 [210]
0.30 [0.012]	13 [0.50]	4.78 [0.188]	1.2 [270]	3	50	2 100	2 000	6.4 [0.25]	6.4 [0.25]	1.93 [0.076]	0.83 [185]	0.89 [200]	1.11 [250]
0.36 [0.014]	13 [0.50]	4.78 [0.188]	1.3 [290]	4	66	2 500	2 200	6.4 [0.25]	6.4 [0.25]	2.08 [0.082]	1.07 [240]	1.11 [250]	1.42 [320]
0.41 [0.016]	13 [0.50]	6.35 [0.250]	1.5 [340]	4	66	3 000	2 500	6.4 [0.25]	7.9 [0.31]	2.24 [0.088]	1.25 [280]	1.33 [300]	1.69 [380]
0.46 [0.018]	13 [0.50]	6.35 [0.250]	1.7 [380]	4	66	3 500	2 800	6.4 [0.25]	7.9 [0.31]	2.36 [0.093]	1.42 [320]	1.60 [360]	2.09 [470]
0.53 [0.021]	13 [0.50]	6.35 [0.250]	1.8 [400]	4	66	4 000	3 200	7.9 [0.31]	7.9 [0.31]	2.54 [0.100]	1.65 [370]	2.09 [470]	2.22 [500]
0.64 [0.025]	13 [0.50]	6.35 [0.250]	2.3 [520]	5	83	5 000	4 100	9.5 [0.37]	11.1 [0.44]	3.05 [0.120]	2.22 [500]	2.67 [600]	3.02 [680]
0.78 [0.031]	13 [0.50]	6.35 [0.250]	2.9 [650]	5	83	6 000	4 800	9.5 [0.37]	12.7 [0.50]	3.30 [0.130]	3.02 [680]	3.56 [800]	4.14 [930]
0.86 [0.034]	13 [0.50]	6.35 [0.250]	3.3 [750]	6	100	7 000	5 500	11.1 [0.44]	14.3 [0.56]	3.81 [0.150]	3.56 [800]	4.09 [920]	4.89 [1100]
1.02 [0.040]	16 [0.63]	6.35 [0.250]	4.0 [900]	6	100	7 800	6 300	11.1 [0.44]	15.9 [0.63]	4.06 [0.160]	4.45 [1000]	5.65 [1270]	6.23 [1400]
1.14 [0.045]	16 [0.63]	6.35 [0.250]	4.4 [1000]	8	133	8 700	7 000	11.1 [0.44]	17.5 [0.69]	4.57 [0.180]	5.34 [1200]	6.45 [1450]	7.56 [1700]
1.27 [0.050]	16 [0.63]	6.35 [0.250]	5.3 [1200]	8	133	9 500	7 500	12.7 [0.50]	19.0 [0.75]	4.83 [0.190]	6.45 [1450]	7.56 [1700]	8.90 [2000]
1.42 [0.056]	16 [0.63]	6.35 [0.250]	6.0 [1350]	10	166	10 300	8 300	14.3 [0.56]	22.2 [0.87]	5.33 [0.210]	7.56 [1700]	8.90 [2000]	10.90 [2450]
1.57 [0.062]	19 [0.75]	6.35 [0.250]	6.7 [1510]	10	166	11 000	9 000	15.9 [0.63]	25.4 [1.00]	5.59 [0.220]	8.67 [1950]	10.67 [2400]	12.90 [2900]
1.78 [0.070]	19 [0.75]	7.95 [0.313]	7.6 [1710]	12	200	12 300	10 000	15.9 [0.63]	28.6 [1.13]	6.35 [0.250]	10.68 [2400]	12.46 [2800]	15.79 [3550]
1.98 [0.078]	19 [0.75]	7.95 [0.313]	8.5 [1910]	14	233	14 000	11 000	17.5 [0.69]	31.8 [1.25]	6.98 [0.275]	12.01 [2700]	16.12 [3400]	17.79 [4000]
2.39 [0.094]	22 [0.88]	7.95 [0.313]	10.7 [2410]	16	266	15 700	12 700	19.0 [0.75]	34.9 [1.37]	7.34 [0.285]	15.79 [3550]	18.68 [4200]	23.58 [5300]
2.77 [0.109]	22 [0.88]	9.53 [0.375]	12.5 [2810]	18	300	17 700	14 000	20.6 [0.81]	38.1 [1.50]	7.37 [0.290]	18.68 [4200]	22.24 [5000]	28.47 [6400]
3.18 [0.125]	22 [0.88]	9.53 [0.375]	14.7 [3300]	20	330	18 000	15 500	22.2 [0.87]	50.8 [2.00]	7.62 [0.300]	22.24 [5000]	26.69[6000]	33.81 [7600]

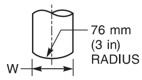
Note: The parameters shown represent a starting point from which the parameters should be established.
[a] Types of steel 200 and 300 series, all grades.
[b] Electrode material RWMA Class 2 or Class 3.
[c] Electrode diameters are based on the following: ISO Standards 13, 16, 19, and 22 mm; RWMA Standards 0.48 (0.50), 0.63, 0.75, 0.88, and 1.00 in.
[d] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz multiply the weld times shown in cycles by 0.83 and round down to the nearest whole number.
[e] For DC welding equipment, lower current settings may be appropriate.

Table 16
Pulsation Spot-Welding Parameters for Stainless Steels[a,b,c]

	Electrode Diameter and Shape[d,e] 			Weld Time[f]	Welding Current (Approximate) Amps			Minimum Weld	Nugget Diameter[f]	Minimum Shear Strength kN [1b]	
				Heat 15 [250] Cycles [ms] / Cool 6 [100] Cycles [ms]	Base Metal Tensile Strength		Minimum Contracting Overlap mm [in] 	Minimum Weld Spacing ℄ to ℄ mm [in]		Base Metal Tensil Strength	
Sheet Thickness Mm [in]	D. mm [in] min.	d. mm [in] max.	Net Electrode Force kN [1b]	Number of Pulsations	Below 1034 MPa [150 ksi]	1034 MPa [150 ksi] and Higher			Minimum mm [in]	Below 1034 MPa	[150 ksi] 1034 MPa [150 ksi] and Higher
3.96 [0.156]	25 [1.00]	12 [0.472]	17.8 [4000]	4	20 700	17 000	31.8 [1.25]	47.6 [1.87]	9.77 [0.385]	33.8 [7600]	44.5 [10 000]
4.76 [0.187]	25 [1.00]	12 [0.472]	22.2 [5000]	5	21 500	18 500	38.1 [1.50]	50.8 [2.00]	10.92 [0.430	43.4 [9760]	54.7 [12 300]
5.16 [0.203]	25 [1.00]	16 [0.630]	24.5 [5500]	6	22 000	19 000	41.3 [1.63]	54.0 [2.13]	11.44 [0.450]	47.2 [10 600]	57.8 [13 000]
6.35 [0.250]	25 [1.00]	16 [0.630]	31.1 [7000]	7	22 500	20 000	44.4 [1.75]	60.3 [2.37]	12.70 [0.500]	60.0 [13 500]	75.6 [17 000]

Note: The parameters shown represent a starting point from which the parameters should be established.
[a] Types of steel 200 and 300 series, all grades.
[b] For DC welding equipment, lower current settings may be appropriate.
[c] Cycles per second or Hz can also be presented in ms [milliseconds].
[d] Electrode material: RWMA Class 2 or Class 3.
[e] Electrode diameters are based on the following: ISO Standards 13, 16, 19, and 22 mm; RWMA Standards 0.48 (0.50), 0.63, 0.75, 0.88, and 1.00 in.
[f] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz multiply the weld times shown in cycles by 0.83 and round down to the nearest whole number.

Table 17
Seam-Welding Parameters for Stainless Steels[a,b]

Sheet Thickness mm [in]	Electrode Width and Shape[c,d]  W mm [in]	Net Electrode Force kN [lb]	On Time Cycles[e]	On Time ms	Off Time for Maximum Speed [Pressure-Tight] Cycles[e]	Off Time for Maximum Speed [Pressure-Tight] ms	Maximum Weld Speed m/min [in/min]	Overlap Welds per Meter [in]	Welding Current [Approx.] Amps	Minimum Contacting Overlap[f] mm [in]
0.15 [0.006]	6 [0.25]	1.33 [300]	2	33	1	16	1.5 [60]	510 [20]	4 000	6.4 [0.25]
0.20 [0.008]	6 [0.25]	1.56 [350]	2	33	1	16	1.7 [67]	460 [18]	4 600	6.4 [0.25]
0.25 [0.010]	6 [0.25]	1.78 [400]	3	50	2	33	1.1 [45]	410 [16]	5 000	6.4 [0.25]
0.30 [0.012]	6 [0.25]	2.00 [450]	3	50	2	33	1.2 [48]	380 [15]	5 600	7.9 [0.31]
0.36 [0.014]	6 [0.25]	2.22 [500]	3	50	2	33	1.3 [51]	360 [14]	6 200	7.9 [0.31]
0.41 [0.016]	6 [0.25]	2.67 [600]	3	50	2	33	1.3 [51]	360 [14]	6 700	7.9 [0.31]
0.46 [0.018]	6 [0.25]	2.89 [650]	3	50	2	33	1.4 [55]	330 [13]	7 300	7.9 [0.31]
0.53 [0.021]	6 [0.25]	3.11 [700]	3	50	2	33	1.4 [55]	330 [13]	7 900	9.5 [0.37]
0.64 [0.025]	10 [0.38]	3.78 [850]	3	50	3	50	1.3 [51]	300 [12]	9 200	11.1 [0.44]
0.78 [0.031]	10 [0.38]	4.45 [1000]	3	50	3	50	1.3 [51]	300 [12]	10 600	11.1 [0.44]
1.02 [0.040]	10 [0.38]	5.78 [1300]	3	50	4	66	1.2 [47]	280 [11]	13 000	12.7 [0.50]
1.27 [0.050]	13 [0.50]	7.12 [1600]	4	66	4	66	1.1 [45]	250 [10]	14 200	15.9 [0.63]
1.57 [0.062]	13 [0.50]	8.23 [1850]	4	66	5	83	1.0 [40]	250 [10]	15 100	15.9 [0.63]
1.78 [0.070]	16 [0.63]	9.56 [2150]	4	66	5	83	1.1 [45]	230 [9]	15 900	17.5 [0.69]
1.98 [0.078]	16 [0.63]	10.23 [2300]	4	66	6	100	1.0 [40]	230 [9]	16 500	17.5 [0.69]
2.39 [0.094]	16 [0.63]	11.34 [2550]	5	83	6	100	0.9 [35]	230 [9]	16 600	19.0 [0.75]
2.77 [0.109]	19 [0.75]	26.47 [5950]	5	83	7	116	1.0 [40]	200 [8]	16 800	20.6 [0.81]
3.18 [0.125]	19 [0.75]	14.68 [3300]	6	100	6	100	1.0 [40]	200 [8]	17 000	22.2 [0.87]

Note: The parameters shown represent a starting point from which the parameters should be established.
[a] Types of steel–301, 302, 303, 304, 308, 309, 310, 316, 317, 321, 347, and 349.
[b] For DC welding equipment, lower current settings may be appropriate.
[c] Electrode material: RWMA Class 3.
[d] Electrode widths are based on the following: ISO Standards 6, 13, 16, 19, and 22 mm; RWMA Standards 0.25, 0.48 (0.50), 0.63, 0.75, 0.88, and 1.00 in.
[e] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz multiply the weld times shown in cycles by 0.83 and round down to the nearest whole number.
[f] For large assemblies, minimum contacting overlap indicated should be increased 30 percent.

Before welding, the surfaces should be clean. Foreign substances can adversely affect the weld consistency. In addition, some can contaminate the welds with such interstitial elements as hydrogen, carbon, and oxygen. Increases in the concentration of these elements can significantly decrease the weld ductility and toughness. Scale-free surfaces may be welded after degreasing or after degreasing plus pickling. Pickling may be carried out in a water solution containing 2–5 percent hydrofluoric acid, and 30–40 percent nitric acid by volume. Pickling acid, hydrofluoric acid, and nitric acid are hazardous to the skin and eyes. Hazardous fumes can be produced by these acids and violent chemical reactions can result when acids are mixed with other chemicals, especially those with basic pHs. Acids can also eat through some clothing.

Use precautions when working near or with acids. Strict precautions are necessary in their use and disposal. Acids should be added to water, not water into acid. Pickling, hydrofluoric, and nitric acids cause chemical burn to the skin. Mix and use pickling acid in a properly vented area. Before use, read and understand the manufacturer's instructions, Safety Data Sheets (SDSs), and your employer's safety practices. Rinse the surfaces in clean water and dry them after pickling.

The data shown in Table 34 may be used as a guide to develop spot welding schedules for titanium alloy 6%Al–4%V.

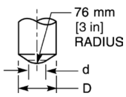
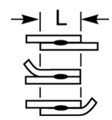
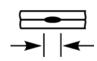
4.7 Welding Data Comments and Discussions Applicable to Various Metals. The following comments and discussions are applicable to the spot- and seam-welding data for all of the following:

(1) Uncoated carbon and HS steels

(2) Coated carbon and HS steels

(3) Aluminum alloys

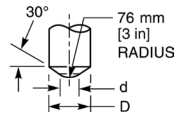
Table 18
Spot-Welding Parameters for Annealed Nickel–Copper Alloy[a] on Single-Phase Equipment[b]

Sheet Thickness mm [in]	Electrode Diameter and Shape[c,d,e]  D mm [in] Min.	d mm [in] Max.	Net Electrode Force kN [lb]	Weld Time[f] Cycles	ms	Welding[b] Current [Approx.] Amps	Minimum Contacting Overlap mm [in] 	Minimum Weld Spacing ℄ to ℄ mm [in]	Nugget Diameter mm [in] 	Minimum Shear Strength kN [lb]
0.13 [0.005] to:										
0.13 [0.005]	13 [0.48]	4.0 [0.16]	0.98 [220]	2	33	5000	6.4 [0.25]	6.4 [0.25]	2.5 [0.10]	0.24 [55]
0.25 [0.010]	13 [0.48]	4.0 [0.16]	0.98 [220]	2	33	6100	6.4 [0.25]	6.4 [0.25]	2.5 [0.10]	0.27 [60]
0.38 [0.015]	13 [0.48]	4.0 [0.16]	0.98 [220]	2	33	7000	6.4 [0.25]	4.8 [0.19]	2.5 [0.10]	0.33 [75]
0.53 [0.021]	13 [0.48]	4.0 [0.16]	0.98 [220]	3	50	7200	6.4 [0.25]	7.9 [0.31]	2.8 [0.11]	0.38 [85]
0.78 [0.031]	13 [0.48]	4.0 [0.16]	1.11 [250]	4	66	7400	6.4 [0.25]	7.9 [0.31]	2.8 [0.11]	0.42 [95]
1.60 [0.063]	13 [0.48]	4.0 [0.16]	1.11 [250]	4	66	8000	6.4 [0.25]	1.11 [0.44]	2.8 [0.11]	0.40 [90]
2.36 [0.098]	16 [0.63]	4.0 [0.16]	1.11 [250]	4	66	8600	6.4 [0.25]	12.7 [0.50]	2.8 [0.11]	0.40 [90]
3.18 [0.125]	16 [0.63]	4.0 [0.16]	1.11 [250]	4	66	8700	6.4 [0.25]	12.7 [0.50]	2.8 [0.11]	0.42 [95]
0.25 [0.010] to:										
0.25 [0.010]	13 [0.48]	4.0 [0.16]	1.20 [270]	2	33	7200	6.4 [0.25]	6.4 [0.25]	3.0 [0.12]	0.64 [140]
0.38 [0.015]	13 [0.48]	4.0 [0.16]	1.25 [280]	2	33	8600	6.4 [0.25]	7.9 [0.31]	3.0 [0.12]	0.69 [155]
0.53 [0.021]	13 [0.48]	4.0 [0.16]	1.25 [280]	3	50	8200	6.4 [0.25]	7.9 [0.31]	3.3 [0.13]	0.76 [170]
0.78 [0.031]	13 [0.48]	4.0 [0.16]	1.33 [300]	4	66	8800	6.4 [0.25]	7.9 [0.31]	3.3 [0.13]	0.85 [190]
1.60 [0.063]	13 [0.48]	4.0 [0.16]	1.33 [300]	4	66	9200	6.4 [0.25]	7.9 [0.31]	3.3 [0.13]	0.85 [190]
2.36 [0.093]	16 [0.63]	4.0 [0.16]	1.45 [330]	4	66	9900	6.4 [0.25]	12.7 [0.50]	3.6 [0.14]	0.93 [210]
3.18 [0.125]	16 [0.63]	4.0 [0.16]	1.45 [330]	4	66	9900	6.4 [0.25]	12.7 [0.50]	3.6 [0.14]	0.98 [220]
0.38 [0.015] to:										
0.38 [0.015]	13 [0.48]	4.8 [0.19]	1.33 [300]	2	33	8600	6.4 [0.25]	7.9 [0.31]	3.3 [0.13]	1.11 [250]
0.53 [0.021]	13 [0.48]	4.8 [0.19]	1.33 [300]	6	100	8200	6.4 [0.25]	9.5 [0.37]	3.3 [0.13]	1.31 [290]
0.78 [0.031]	13 [0.48]	4.8 [0.19]	1.45 [330]	6	100	9300	6.4 [0.25]	9.5 [0.37]	3.3 [0.13]	1.33 [300]
1.60 [0.063]	16 [0.63]	4.8 [0.19]	1.45 [330]	6	100	9400	6.4 [0.25]	11.1 [0.44]	3.6 [0.14]	1.56 [350]
2.36 [0.093]	16 [0.63]	4.8 [0.19]	1.45 [330]	6	100	9500	6.4 [0.25]	12.7 [0.50]	3.6 [0.14]	1.60 [360]
3.18 [0.125]	16 [0.63]	4.8 [0.19]	1.45 [330]	6	100	9500	6.4 [0.25]	12.7 [0.50]	3.6 [0.14]	1.62 [364]
0.53 [0.021] to:										
0.53 [0.021]	13 [0.48]	4.8 [0.19]	1.33 [300]	12	200	6200	7.9 [0.31]	11.1 [0.44]	3.3 [0.13]	200 [450]
0.78 [0.031]	13 [0.48]	4.8 [0.19]	1.45 [330]	12	200	6800	7.9 [0.31]	11.1 [0.44]	3.3 [0.13]	2.05 [460]
1.60 [0.063]	16 [0.63]	4.8 [0.19]	1.45 [330]	12	200	7200	7.9 [0.31]	12.7 [0.50]	3.6 [0.14]	2.22 [500]
2.36 [0.093]	16 [0.63]	4.8 [0.19]	1.45 [330]	12	200	7700	9.5 [0.37]	14.3 [0.56]	3.6 [0.14]	2.36 [530]
3.18 [0.125]	16 [0.63]	4.8 [0.19]	1.45 [330]	12	200	8200	9.5 [0.37]	14.3 [0.56]	3.6 [0.14]	2.45 [550]
0.78 [0.031] to:										
0.78 [0.031]	19 [0.75]	4.8 [0.19]	3.11 [700]	12	200	10500	9.5 [0.37]	16.0 [0.63]	4.3 [0.17]	3.76 [845]
1.60 [0.063]	19 [0.75]	4.8 [0.19]	3.34 [750]	12	200	11200	12.7 [0.50]	17.5 [0.69]	4.6 [0.18]	4.05 [910]
2.36 [0.098]	19 [0.75]	4.8 [0.19]	3.45 [780]	12	200	11400	12.7 [0.50]	19.0 [0.75]	4.8 [0.19]	4.60 [1034]
3.18 [0.125]	19 [0.75]	4.8 [0.19]	3.45 [780]	12	200	11800	12.7 [0.50]	19.0 [0.75]	4.8 [0.19]	4.78 [1075]
1.60 [0.063] to:										
1.60 [0.063]	19 [0.75]	7.9 [0.31]	12.01[2700]	12	200	15300	16.0 [0.63]	28.6 [1.13]	7.9 [0.31]	9.16 [2060]
2.36 [0.093]	19 [0.75]	7.9 [0.31]	12.01[2700]	12	200	15900	16.0 [0.63]	30.2 [1.19]	7.9 [0.31]	9.70 [2180]
3.18 [0.125]	19 [0.75]	7.9 [0.31]	12.01[2700]	12	200	16200	16.0 [0.63]	31.8 [1.25]	8.1 [0.32]	10.50 [2360]
2.36 [0.093] to:										
2.36 [0.093]	[0.88]	9.5 [0.37]	12.28[2760]	20	333	22600	19.0 [0.75]	31.8 [1.25]	9.4 [0.37]	17.26 [3880]
3.18 [0.125]	[0.88]	9.5 [0.37]	12.28[2760]	20	333	25000	19.0 [0.75]	31.8 [1.25	9.7 [0.38]	19.53 [4390]
3.18 [0.125] to:										
3.18 [0.125]	special	12.7 [0.50]	22.24[5000]	30	500	30000	22.2 [0.87]	41.3 [1.63]	11.9[0.47]	26.02 [5850]

Note: The parameters shown represent a starting point from which a weld schedule can be established.
[a] Nominal chemical composition of nickel–copper alloy (UNS N04400), wt %. 66.0 Ni, 31.5 Cu, 1.35 Fe, 0.90 Mn, 0.15 Si, 0.12 C, 0.005 S.
[b] For DC welding equipment, lower current settings may be appropriate.
[c] Electrode shape may be flat rather than domed, in which case the shear strengths and nugget diameters will be higher and larger than shown in the table.
[d] Electrode material: RWMA Class 1 or Class 2.
[e] Electrode diameters are based on the following: ISO Standards 13, 16, 19, and 22 mm; RWMA Standards 0.48 (0.50), 0.63, 0.75, 0.88, and 1.00 in.
[f] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz multiply the weld times shown in cycles by 0.83 and round down to the nearest whole number.

Table 19
Spot-Welding Parameters for Annealed Nickel–Copper Alloy on Three-Phase Frequency Converter Machines[a]

Electrode Diameter and Shape[b,c]



Sheet Thickness mm [in]	Electrode Diameter and Shape[b,c]: D mm [in] Min.	Radius mm [in]	d mm [in] Max.	Net Electrode Force kN [lb]	Weld Time[d,e] Cycles[d] [ms]: Heat Cycles [ms]	Cool Cycles [ms]	Pulses	Welding Current [Approx.] Amps	Minimum Contacting Overlap mm [in]	Minimum Weld Spacing ℄ to ℄ mm [in]	Nugget Diameter mm [in]	Minimum Tension Shear Strength kN [lb]
0.46 [0.018]	13 [0.50]	76 [3.0]	4.8 [0.19]	1.8 [400]	6 [100]	1 [16]	2	4300	9.5 [0.37]	9.5 [0.37]	4.3 [0.17]	1.8 [400]
0.76 [0.030]	13 [0.50]	127 [5.0]	6.4 [0.25]	3.6 [800]	6 [100]	1 [16]	2	8500	11.1 [0.44]	16.0 [0.63]	4.6 [0.18]	4.0 [900]
1.09 [0.043]	13 [0.50]	127 [5.0]	6.4 [0.25]	7.1 [1600]	8 [133]	1 [16]	2	11500	12.7 [0.50]	19.0 [0.75]	6.6 [0.26]	7.8 [1750]
1.57 [0.062]	16 [0.63]	178 [7.0]	7.9 [0.31]	9.8 [2200]	10 [166]	1 [16]	2	14000	16.0 [0.63]	28.5 [1.13]	8.1 [0.32]	9.1 [2050]
2.36 [0.093]	22 [0.88]	229 [9.0]	11.1 [0.31]	16.9 [3800]	9 [150]	1 [16]	4	22500	19.0 [0.75]	31.8 [1.25]	10.2 [0.40]	24.0 [5400]
3.18 [0.125]	22 [0.88]	305 [12.0]	12.7 [0.50]	22.2 [5000]	10 [166]	1 [16]	6	31000	22.2 [0.87]	41.3 [1.63]	12.2 [0.48]	31.1 [7000]

Note: The parameters shown represent a starting point from which a weld schedule can be established.

[a] Nominal chemical composition of nickel–copper alloy (UNS N04400), wt %: 66.0 Ni, 31.5 Cu, 1.35 Fe, 0.90 Mn, 0.15 Si, 0.12 C, 0.005 S.

[b] Electrode diameters are based on the following: ISO Standards 13, 16, 19, and 22 mm; RWMA Standards 0.48 (0.50), 0.63, 0.75, 0.88, and 1.00 in.

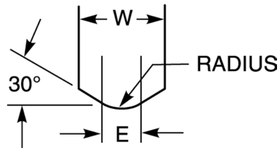
[c] Electrode material: RWMA Class 1.

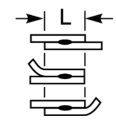
[d] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz equipment, multiply the weld times shown in cycles by 0.83, then round down to the nearest whole number.

[e] Weld time based on 10-cycle machine. For 5-cycle machine, adjust accordingly to establish total equivalent on time with minimum of cool time.

Table 20
Seam-Welding Parameters for Annealed Nickel–Copper Alloy[a] on Single-Phase Equipment

Electrode Wheel Width and Shape[b,c]



				Net			Off Time			Minimum Contacting Overlap mm [in]
Sheet Thickness mm [in]	W mm [in] Min.	E mm [in] Max.	Radius mm [in]	Electrode Force kN [lb]	On Time Cycles[d] [ms]	Pressure Tight Cycles[d] [ms]	Weld Speed mm/min [in/min]	Welds per meter [in]	Welding Current [Approx.] Amps	
0.25 [0.010]	10 [0.38]	4.0 [0.16]	76 [3.0]	8.9 [200]	1 [16]	3 [50]	1905 [75]	472 [12]	5300	6.4 [0.25]
0.38 [0.015]	10 [0.38]	4.0 [0.16]	152 [6.0]	13.3 [300]	1 [16]	3 [50]	1905 [75]	472 [12]	7600	6.4 [0.25
0.53 [0.021]	10 [0.38]	4.8 [0.19]	152 [6.0]	22.2 [500]	2 [33]	6 [100]	965 [38]	472 [12]	8700	7.9 [0.31]
0.64 [0.025]	10 [0.38]	4.8 [0.19]	152 [6.0]	2.67 [600]	3 [50]	12 [200]	508 [20]	472 [12]	9500	7.9 [0.31
0.79 [0.031]	10 [0.38]	4.8 [0.19]	152 [6.0]	3.11 [700]	4 [66]	12 [200]	483 [19]	472 [12]	10000	9.5 [0.37]
1.57 [0.063]	13 [0.50]	9.5 [0.37]	152 [6.0]	11.1 [2500]	8 [133]	12 [200]	508 [20]	350 [9]	19000	16.0 [0.63]

Note: The parameters shown represent a starting point from which a weld schedule can be established.
[a] Nominal chemical composition of nickel–copper alloy (UNS N04400), wt %: 66.0Ni, 31.5 Cu, 1.35Fe, 0.90 Mn, 0.15 Si, 0.12 C, 0.005 S.
[b] Electrode material: RWMA Class 1.
[c] Electrode widths are based on the following: ISO Standards 10, 13, 16, 19, and 22 mm; RWMA Standards 0.38, 0.48 (0.50), 0.63, 0.75, 0.88 and 1.00 in.
[d] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz equipment, multiply the weld times shown in cycles by 0.83, then round down to the nearest whole number.

(4) Stainless steels, nickel, nickel-base and cobalt-base alloys

(5) Copper and copper alloys

(6) Titanium and titanium alloys

4.7.1 Spot-Welding Electrode Face Diameter. The electrode face diameter affects the electrode pressure and current density experienced by the weld nugget being formed. Face diameters greater than those recommended in the tables will reduce current density and electrode pressure. Similar results occur when the electrode face diameter increases in size during welding due to wear and deformation. Electrode face diameters smaller than those recommended may result in expulsion, excessive indentation or electrode sticking. Electrode face diameters other than those presented in the tables may be used. However, the welding schedule must be adjusted accordingly (See Figure 2 and Table 35).

Care should be exercised to prevent excessive increase or decrease in the face diameter during electrode dressing. Where a flat-face electrode is used, the face diameter should not exceed the value given in order to control the electrode contact area.

4.7.2 Electrode Face Width (Seam Welding). Electrode wheels are used in seam welding. Therefore, electrode face width, rather than electrode face diameter, is specified in seam welding.

4.7.3 Electrode Face Shape. The electrode face shape influences the weld size, shape, and surface indentation. To maintain consistent weld quality, the electrodes may require redressing after a limited number of welds to maintain their geometric shape and proper face area, and to minimize contact resistance between the work and electrode. The size of the electrode face and its shape influence both current density intensity of heat generation and also the conduction of heat away from the weld zone. Both factors contribute towards the location of the nugget and nugget penetration.

For special combinations, such as unequal thicknesses, it is often desirable to use a combination of electrode sizes, configurations, or contours to produce acceptable welds. The objective of changing the geometry of the electrode(s) is to establish a combination that brings the faying surfaces of the workpieces simultaneously to the required temperature, or to define which of the component or surface of the weldment will show shrinkage or distortion.

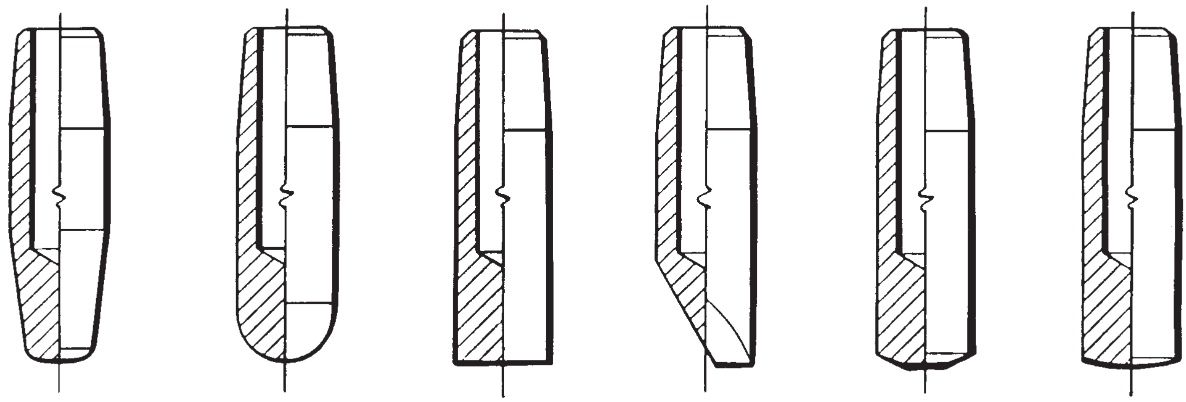


Figure 2—Standard RWMA Nose or Tip Geometries of Spot-Welding Electrodes

(1) Electrode Sizes. The main tool to achieve heat balance at the faying surface is current density. At a given secondary current, an electrode with a large contact surface will have a lower current density (i.e., welding current per unit surface area) than an electrode with a small contact area. An example of how this is applied is placing a large electrode face against a thin sheet and a small electrode face against the thicker sheet. When the welding current flows in this circuit, the thicker sheet will be heated faster than the thin sheet. If the combination is correct, the two workpieces will reach the desired temperature at the same time and the weld will form at the faying surface.

(2) Electrode Configuration. The electrode profile, including the proximity of water cooling to the weld face, will determine such process attributes as electrode cooling and wear rate. The mass of copper in the electrode will determine the rate of heating and cooling in the electrode. The rate of heating in the electrode can be used to supplement the heat in the workpieces or alter the rate of cooling of the weldment. An electrode with a lot of mass will take longer to heat up and cool down than an electrode with lower mass. Changing the depth of the waterhole will similarly alter the transmission of heat to the cooling water.

(3) Electrode Contour. The weld face contour is changed to control the contact force at the sheet and/or faying surface. When trying to find the balance between electrode contact area and force density (electrode force per unit area) it is common to add a weld face radius or contour. The contour governs the rate the contact area changes over time while the electrodes indent into the softened workpiece (s). A contour with a large radius will increase the contact area quickly, thereby maintaining the seal around the molten nugget at the faying surface or to decrease the force density is beneficial when welding very hard materials or very soft materials. The point load applied initially by the radiused contour helps to distort the sheet and create a concentrated point of contact at the faying surface. The larger contact area helps distribute the force on the electrode to increase its service life and it minimizes the distortion of the sheets as they soften during the weld. This is especially important for thick and/or hard materials requiring substantial electrode forces, or when welding ductile workpiece materials such as aluminum.

Standard RWMA nose or tip geometries of spot-welding electrodes are shown in Figure 2, and Female Electrode caps in Figure 3.

4.7.4 Electrode Cooling. Spot- and projection-welding electrodes should be internally water cooled to prevent overheating which results in electrode sticking and decreased electrode life. Internal coolant flow rate requirements may vary from approximately 2 to 6 L/min [0.50–1.50 gal/min] per electrode, depending on the type of welding system. Water coolant temperature should be less than 30°C [86°F]. For adequate cooling, a maximum electrode face thickness (nose thickness) of 13 mm [0.50 in] with a properly positioned coolant inlet tube is recommended. The coolant inlet tube should be cut on an angle at the tip and inserted to contact the bottom of the water hole in the electrode to ensure maximum cooling of the face. If the coolant inlet tube is not properly placed, steam or turbulence may develop within the electrode tip, reducing heat dissipation. The reduced cooling of the electrode will decrease the electrode life.

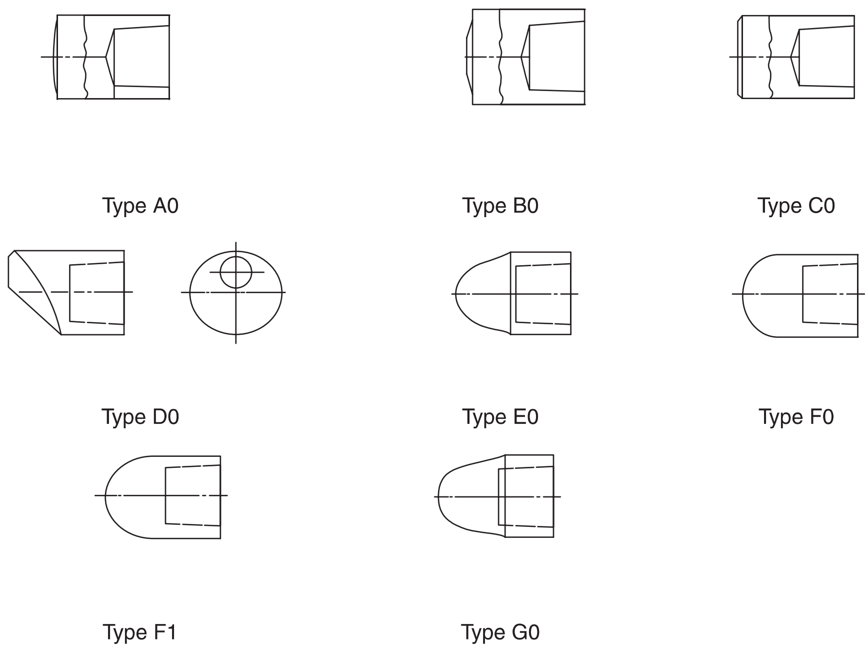


Figure 3—ISO 5821 Female Electrode Cap Designations

It is possible to apply external water cooling alone or in combination with internal water cooling of resistance welding electrodes. External water cooling can be applied by an external water stream or by immersion. Before external cooling is employed, the weld cooling rate effects should be evaluated to make sure the weldment properties have not been negatively affected. Corrosion prevention or remediation may also need to be addressed.

4.7.5 Net Electrode Force. Correct weld forces, for a given combination of current level and weld time, are required to produce welds of optimum nugget size and penetration without expulsion, porosity, cracking, or excessive indentation. Excessively low forces do not provide current uniformity and molten metal containment, and may result in expulsion at the joint or electrode-to-workpiece interface. Excessively high forces produce metal indentation, distortion, and a small weld nugget diameter.

As the electrode force increases, the resistance values of the workpiece circuit will decrease. Lower resistance values require higher current levels in order to provide proper heating of the faying interface to create a proper weld nugget. Therefore, a correct balance of current, weld time, and electrode force is necessary.

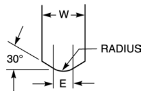
Electrode alignment is necessary for proper weld force application. Nonparallel electrode faces can result in a limited electrode tip contact area, which will experience a large effective weld pressure. The nonuniform application of weld force may result in excessive surface indentation, localized overheating, expulsion, or undersized weld nuggets. Axial misalignment of electrodes may produce similar results. Further, electrode wear may alter the effective electrode pressure if the electrode face area increases or decreases.

When a forging force is employed to prevent weld nugget cracking in resistance seam welding, an intermittent drive is used so that the forging force is applied directly over the intended weld nugget. When an intermittent drive is used, the electrode wheels are stopped for each weld nugget.

4.7.6 Weld Schedule Times. Properly set times contribute to high quality resistance welding. The values shown for all times are in cycles based on 60 cycles per second. Some of the time variables discussed below are usually part of the welding schedules, but are not necessarily shown in the table.

Table 21
Seam-Welding Parameters for Annealed Nickel–Copper Alloy[a] on Three-Phase Frequency Converter Machines

Electrode Wheel Width and Shape[b,c]

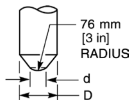


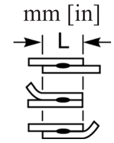
Sheet Thickness mm [in]	Intermittent Drive[d]									Motor On Time Cycles[e] [ms]	Weld Speed [Approx.] mm/min [in/min]	Welds per meter [in]	Welding Current [Approx.] Amps	Postheat Current [Approx.] Amps	Nugget Width mm [in]	Minimum Contacting Overlap mm [in]
	W mm [in] Min.	E mm [in] Max.	Radius mm [in]	Net Electrode Force kN [lb]	On Time Cycles[e] [ms]	Off Time or Interpulse Time Cycles[e] [ms]	Weld pulses	Quench Time Cycles[e] [ms]	Posts Heat Pulses	Forge Time Cycles[e] [ms]							
0.46 [0.018]	10 [0.38]	6.4 [0.25]	76 [3.0]	3.6 [800]	5 [83]	1 [16]	1	6 [100]	1	5 [83]	15 [250]	145 [5.7]	669 [17]	4500	2000	4.1 [0.16]	9.5 [0.37]
0.64 [0.025]	10 [0.38]	6.4 [0.25]	76 [3.0]	4.9 [1100]	5 [83]	1 [16]	1	6 [100]	1	5 [83]	15 [250]	152 [6.0]	630 [16]	6200	3100	4.6 [0.18]	11.1 [0.44]
0.79 [0.031]	10 [0.38]	7.9 [0.31]	127 [5.0]	6.7 [1500]	5 [83]	1 [16]	1	6 [100]	1	5 [83]	15 [250]	165 [6.5]	591 [15]	8500	4000	5.3 [0.21]	12.7 [0.50]
1.09 [0.043]	13 [0.50]	9.5 [0.37]	127 [5.0]	8.0 [1800]	6 [100]	1 [16]	1	6 [100]	1	5 [83]	15 [250]	165 [6.5]	551 [14]	11000	5700	6.1 [0.24]	12.7 [0.50]
1.57 [0.062]	13 [0.50]	9.5 [0.37]	127 [5.0]	9.3 [2090]	5 [83]	2 [33]	2	7 [116]	2	5 [83]	15 [250]	142 [5.6]	472 [12]	14000	6800	7.1 [0.28]	16.0 [0.63]
2.36 [0.093]	19 [0.75]	11.1 [0.44]	127 [5.0]	12.0 [2700]	6 [100]	2 [33]	2	8 [133]	4	10 [166]	15 [250]	94 [3.7]	472 [12]	21000	10500	7.6 [0.30]	16.0 [0.63]
3.18 [0.125]	19 [0.75]	12.7 [0.50]	127 [5.0]	14.2 [3190]	6 [100]	2 [33]	4	8 [133]	4	10 [166]	15 [250]	94 [3.7]	394 [10]	25500	12600	8.1 [0.32]	16.0 [0.63]

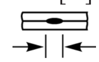
[a] Nominal chemical composition of nickel–copper alloy (UNS N04400), wt %: 66.0 Ni, 31.5 Cu, 1.35 Fe, 0.90 Mn, 0.15 Si, 0.12 C, 0.005 S.
[b] Electrode material: RWMA Class 1.
[c] Electrode widths are based on the following: ISO Standards 10, 13, 16, 19, and 22 mm; RWMA Standards 0.38, 0.48 (0.50), 0.63, 0.75, 0.88, and 1.00 in.
[d] Intermittent welding motion recommended for all thicknesses.
[e] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz equipment, multiply the weld times shown in cycles by 0.83, then round down to the nearest whole number.

Notes:
1. The parameters shown represent a starting point from which a weld schedule can be established.
2. Burnished electrodes recommended for thicknesses 0.79 mm (0.031 in) and under. (Burnishing of electrodes is a method of surface finishing used principally to improve the coined finish on the face of the electrode. It consists of rolling the face of the electrode to the desired shape until the surface becomes smooth, hardened to some extent and accurately shaped).
3. Electrode contact surfaces must be clean to prevent surface pick-up.
4. Weld time based on 20 cycle machine. For machines with limited on-time, heat and cool times should be adjusted accordingly.

Table 22
Spot-Welding Parameters for Annealed Nickel–Copper Alloy 600[a] on Single-Phase Equipment





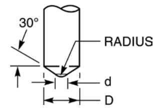


Sheet Thickness mm [in]	Electrode Diameter and Shape[b,c,d,e] D mm [in] Min.	d mm [in] Max.	Net Electrode Force kN [lb]	Weld Time[f] Cycles [ms]	Welding Current [Approx.] Amps	Minimum Contacting Overlap mm [in]	Minimum Weld Spacing ℄ to ℄ mm [in]	Nugget Diameter mm [in]	Minimum Shear Strength kN [lb]
0.13 [0.005] to:									
0.13 [0.005]	6 [0.25]	4.0 [0.16]	1.34 [300]	2 [33]	7 000	6.4 [0.25]	6.4 [0.25]	2.8 [0.11]	0.3 [700]
0.25 [0.010]	6 [0.25]	4.0 [0.16]	1.34 [300]	4 [66]	5 300	6.4 [0.25]	6.4 [0.25]	3.0 [0.12]	0.44 [100]
0.38 [0.015]	6 [0.25]	4.0 [0.16]	1.34 [300]	4 [66]	5 500	6.4 [0.25]	6.4 [0.25]	3.0 [0.12]	0.47 [106]
0.53 [0.021]	6 [0.25]	4.0 [0.16]	1.34 [300]	6 [100]	4 800	6.4 [0.25]	7.9 [0.31]	3.3 [0.13]	0.49 [110]
0.79 [0.031]	6 [0.25]	4.0 [0.16]	1.45 [326]	6 [100]	5 400	6.4 [0.25]	7.9 [0.31]	3.3 [0.13]	0.53 [120]
1.6 [0.063]	16 [0.63]	4.0 [0.16]	1.45 [326]	6 [100]	5 600	6.4 [0.25]	9.5 [0.37]	3.8 [0.15]	0.60 [130]
2.4 [0.098]	16 [0.63]	4.0 [0.16]	1.45 [326]	6 [100]	5 800	6.4 [0.25]	9.5 [0.37]	4.1 [0.16]	0.65 [150]
3.2 [0.125]	16 [0.63]	4.0 [0.16]	1.45 [326]	6 [100]	5 600	6.4 [0.25]	9.5 [0.37]	3.8 [0.15]	0.60 [130]
0.25 [0.010] to:									
0.25 [0.010]	6 [0.25]	4.0 [0.16]	1.42 [320]	4 [66]	7 900	6.4 [0.25]	6.4 [0.25]	3.0 [0.12]	0.78 [175]
0.38 [0.015]	6 [0.25]	4.0 [0.16]	1.42 [320]	4 [66]	5 500	6.4 [0.25]	6.4 [0.25]	3.3 [0.13]	0.96 [220]
0.53 [0.021]	6 [0.25]	4.0 [0.16]	1.42 [320]	6 [100]	5 100	6.4 [0.25]	7.1 [0.28]	3.3 [0.13]	0.96 [220]
0.79 [0.031]	6 [0.25]	4.0 [0.16]	1.56 [350]	6 [100]	5 600	6.4 [0.25]	7.1 [0.28]	3.3 [0.13]	1.29 [290]
1.6 [0.063]	6 [0.25]	4.0 [0.16]	1.78 [400]	6 [100]	5 500	6.4 [0.25]	7.9 [0.31]	3.6 [0.14]	1.40 [315]
2.4 [0.093]	16 [0.63]	4.0 [0.16]	1.78 [400]	6 [100]	5 800	6.4 [0.25]	9.5 [0.37]	3.8 [0.15]	1.56 [350]
3.2 [0.125]	16 [0.63]	4.0 [0.16]	1.78 [400]	6 [100]	4 600	6.4 [0.25]	9.5 [0.37]	3.6 [0.14]	1.65 [370]
0.38 [0.015] to:									
0.38 [0.015]	6 [0.25]	4.8 [0.19]	1.60 [360]	6 [100]	7 600	6.4 [0.25]	6.4 [0.25]	3.0 [0.12]	1.31 [294]
0.53 [0.021]	6 [0.25]	4.8 [0.19]	1.60 [360]	6 [100]	8 400	6.4 [0.25]	6.4 [0.25]	3.0 [0.12]	1.29 [290]
0.79 [0.031]	6 [0.25]	4.8 [0.19]	1.78 [400]	8 [133]	4 600	6.4 [0.25]	7.1 [0.28]	3.3 [0.13]	1.65 [370]
1.6 [0.063]	10 [0.38]	4.8 [0.19]	1.78 [400]	8 [133]	4 700	6.4 [0.25]	7.9 [0.31]	3.3 [0.13]	1.96 [440]
2.4 [0.093]	16 [0.63]	4.8 [0.19]	1.78 [400]	10 [166]	4 700	6.4 [0.25]	8.7 [0.34]	4.1 [0.16]	2.38 [535]
3.2 [0.125]	16 [0.63]	4.8 [0.19]	1.78 [400]	12 [200]	4 600	6.4 [0.25]	9.5 [0.37]	4.1 [0.16]	2.49 [560]
0.53 [0.021] to:									
0.53 [0.021]	6 [0.25]	4.8 [0.19]	1.34 [300]	12 [200]	4 000	7.9 [0.31]	11.1 [0.44]	3.0 [0.12]	2.42 [544]
0.79 [0.031]	6 [0.25]	4.8 [0.19]	1.56 [350]	12 [200]	4 100	7.9 [0.31]	11.1 [0.44]	3.0 [0.12]	2.38 [535]
1.6 [0.063]	6 [0.25]	4.8 [0.19]	1.78 [400]	12 [200]	5 300	7.9 [0.31]	11.9 [0.47]	3.0 [0.12]	2.58 [580]
2.4 [0.093]	16 [0.63]	4.8 [0.19]	2.22 [500]	12 [200]	5 900	7.9 [0.31]	12.7 [0.50]	3.8 [0.15]	2.98 [670]
3.2 [0.125]	16 [0.63]	4.8 [0.19]	2.45 [550]	12 [200]	6 300	7.9 [0.31]	12.7 [0.50]	3.8 [0.15]	3.07 [690]
0.79 [0.031] to:									
0.79 [0.031]	6 [0.25]	4.8 [0.19]	3.11 [700]	12 [200]	6 700	9.5 [0.37]	14.3 [0.56]	4.6 [0.18]	4.09 [920]
1.6 [0.063]	10 [0.37]	4.8 [0.19]	3.11 [700]	12 [200]	7 100	9.5 [0.37]	16.0 [0.63]	4.6 [0.18]	4.29 [964]
2.4 [0.093]	10 [0.37]	4.8 [0.19]	3.11 [700]	12 [200]	8 300	9.5 [0.37]	17.5 [0.69]	5.1 [0.20]	5.74 [1290]
3.2 [0.125]	16 [0.63]	4.8 [0.19]	3.34 [750]	12 [200]	8 900	9.5 [0.37]	19.0 [0.75]	5.1 [0.20]	5.38 [1210]
1.6 [0.063] to:									
1.6 [0.063]	10 [0.37]	4.8 [0.19]	9.21 [2070]	12 [200]	12 000	16.0 [0.63]	28.6 [1.13]	7.9 [0.31]	12.41 [2790]
2.4 [0.093]	16 [0.63]	7.9 [0.31]	10.90 [2450]	16 [266]	12 000	16.0 [0.63]	30.2 [1.19]	7.9 [0.31]	12.23 [2750]
3.2 [0.125]	16 [0.63]	14.3 [0.56]	11.57 [2600]	20 [333]	12 000	16.0 [0.63]	31.8 [1.25]	8.1 [0.32]	15.21 [3420]
2.4 [0.093] to:									
2.4 [0.093]	10 [0.37]	9.5 [0.37]	17.21 [3870]	20 [333]	19 000	19.0 [0.75]	30.2 [1.19]	9.4 [0.37]	19.57 [4400]
3.2 [0.125]	10 [0.37]	11.1 [0.44]	22.69 [5100]	30 [500]	20 000	19.0 [0.75]	31.8 [1.25	10.2 [0.40]	20.91 [4700]
3.2 [0.125] to:									
3.2 [0.125]	10 [0.37]	11.1 [0.44]	23.44 [5270]	30 [500]	20 100	22.2 [0.87]	33.3 [1.31]	11.1 [0.44]	28.47 [6400]

Note: The parameters shown represent a starting point from which a weld schedule can be established.
[a] Nominal chemical composition of nickel–chromium alloy 600 (UNS 06600), wt %: 76.0 Ni, 15.8 Cr, 7.20 Fe, 0.04 C, 0.20 Mn, 0.10 Cu, 0.04 C, 0.007 Si.
[b] Electrode shape may be flat rather than domed in which case the shear strengths and nugget diameters will be higher and larger than shown in the table.
[c] Electrode material: RWMA Class 2, Class 3, or Class 4.
[d] Indicates molybdenum-tipped electrode.
[g] Electrode widths are based on the following: ISO Standards 6, 10, 13, 16, 19, and 22 mm; RWMA Standards 0.25, 0.38, 0.48 (0.50), 0.63, 0.75, 0.88, and 1.00 in.
[f] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz equipment, multiply the weld times shown in cycles by 0.83, then round down to the nearest whole number.

Table 23
Spot-Welding Parameters for Annealed Nickel–Chromium Alloy X750[a] on Single-Phase Equipment[b]

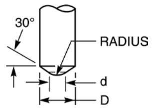
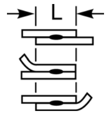
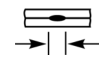
Electrode Diameter and Shape[c,d]



Sheet Thickness mm [in]	D mm [in] Min.	Radius mm [in]	d mm [in] Max.	Net Electrode Force kN [lb]	Weld Time Cycles[e] [ms]	Welding Current [Approx.] Amps	Minimum Contacting Overlap mm [in]	Minimum Weld Spacing ℄ to ℄ mm [in]	Nugget Diameter mm [in]	Minimum Tension Shear Strength kN [klb] As Welded	Minimum Tension Shear Strength kN [klb] Aged 4 hours at 700°C [1300°F]	Minimum Cross Tension Strength kN [klb] As Welded	Minimum Cross Tension Strength kN [klb] Aged 4 hours at 700°C [1300°F]
0.25 [0.010]	13 [0.50]	150 [6.0]	4.0 [0.16]	1.33 [300]	2 [33]	7 300	6.4 [0.25]	6.4 [0.25]	2.8 [0.11]	1.13 [0.25]	1.65 [0.37]	0.93 [0.21]	0.65 [0.15]
0.38 [0.015]	13 [0.50]	150 [6.0]	4.0 [0.16]	1.78 [400]	4 [66]	7 400	6.4 [0.25]	6.4 [0.25]	2.8 [0.11]	1.82 [0.41]	2.49 [0.56]	1.31 [0.29]	0.96 [0.22]
0.53 [0.021]	13 [0.50]	150 [6.0]	4.7 [0.19]	3.34 [750]	6 [100]	7 500	9.5 [0.37]	11.1 [0.44]	3.6 [0.14]	2.36 [0.53]	3.20 [0.72]	1.82 [0.41]	1.29 [0.29]
0.79 [0.031]	19 [0.63]	150 [6.0]	5.6 [0.22]	7.78 [1750]	8 [133]	9 900	11.1 [0.44]	19.0 [0.75]	4.3 [0.17]	5.34 [1.20]	6.41 [1.44]	3.56 [0.80]	2.42 [0.54]
1.57 [0.062]	22 [0.88]	254 [10.0]	7.9 [0.31]	19.54 [4000]	16 [266]	16 350	19.9 [0.63]	28.6 [1.13]	7.4 [0.29]	15.34 [3.45]	20.02 [4.50]	12.01 [2.70]	8.45 [1.90]

Note: The parameters shown represent a starting point from which a weld schedule can be established.
[a] Nominal chemical composition of nickel–chromium ally X750 [UNS N07750], wt %: 73.0 Ni, 15.5 Cr, 6.75 Fe, 2.50 Ti, 0.85 Cb, 0.80 AI, 0.70 Mn, 0.05 Cu, 0.04 C, 0.030 Si, 0.007 S.
[b] For DC welding equipment, lower current settings may be appropriate.
[c] Electrode material: RWMA Class 2 or Class 3.
[d] Electrode widths are based on the following: ISO Standards 13, 16, 19, and 22 mm; RWMA Standards 0.48 (0.50), 0.63, 0.75, 0.88, and 1.00 in.
[e] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz multiply the weld times shown in cycles by 0.83 and round down to the nearest whole number.

Table 24
Spot-Welding Parameters for Annealed Nickel–Chromium Alloy X750[a] on Three-Phase Frequency Converter Machines[b]

Electrode Diameter and Shape[c,d] 					Weld Time[e,f] Cycles[f] [ms]				Minimum Contacting Overlap mm [in] 		Nugget Diameter mm [in] 	
Sheet Thickness mm [in]	D mm [in] Min.	Radius mm [in]	d mm [in] Max.	Net Electrode Force kN [lb]	Heat Cyles [ms]	Cool Cyles [ms]	Pulses	Welding Current [Approx.] Amps		Minimum Weld Spacing ℄ to ℄ mm [in]		Minimum Tension Shear Strength kN [klb]
0.64 [0.025]	13 [0.50]	76 [3.0]	5.6 [0.22]	8.9 [2000]	8 [133]	1 [16]	1	6 000	9.5 [0.37]	16.0 [0.63]	4.1 [0.16]	4.00 [900]
0.79 [0.031]	16 [0.63]	127 [5.0]	6.4 [0.25]	9.8 [2200]	9 [150]	1 [16]	1	6 800	11.1 [0.44]	19.0 [0.75]	4.6 [0.18]	5.12 [1150]
1.09 [0.043]	16 [0.63]	127 [5.0]	6.4 [0.25]	12.0 [2700]	5 [83]	1 [16]	4	8 100	12.7 [0.50]	25.4 [1.00]	5.1 [0.20]	8.01 [1800]
1.57 [0.062]	22 [0.88]	203 [8.0]	7.9 [0.31]	15.6 [3510]	8 [133]	1 [16]	4	11 400	9.5 [0.37]	32.8 [1.25]	6.4 [0.25]	14.68 [3300]
2.36 [0.093]	22 [0.88]	203 [8.0]	11.1 [0.44]	22.2 [4990]	8 [133]	1 [16]	6	15 000	19.0 [0.75]	38.1 [1.50]	9.4 [0.37]	25.35 [5700]

Note: The parameters shown represent a starting point from which a weld schedule can be established.

[a] Nominal chemical composition of nickel–chromium alloy X750 (UNS N07750), wt %: 73.0 Ni, 15.5 Cr, 6.75 Fe, 2.50 Ti, 0.85 Cb, 0.80 Al, 0.70 Mn, 0.05 Cu, 0.04 C, 0.030 Si, 0.007 S.

[b] For DC welding equipment, lower current settings may be appropriate.

[c] Electrode material: RWMA Class 2 or Class 3.

[d] Electrode widths are based on the following: ISO Standards 13, 16, 19, and 22 mm; RWMA Standards 0.48 (0.50), 0.63, 0.75, 0.88, and 1.00 in.

[e] Weld time based on 10-cycle machine. For 5-cycle machine, adjust accordingly to establish total equivalent on time with minimum of cool time.

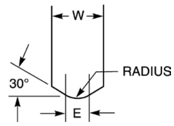
[f] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz multiply the weld times shown in cycles by 0.83 and round down to the nearest whole number.

Table 25
Spot-Welding Parameters for Annealed Nickel–Chromium Alloy X750[a] on Three-Phase Dry Disk Rectifier Machines[b]

Sheet Thickness mm [in]	Electrode Diameter and Shape[c,d] D mm [in] Min.	Electrode Diameter and Shape[c,d] Radius mm [in]	Net Electrode Force Weld kN [lb]	Net Electrode Force Forge kN [lb]	Forge Delay Time Cycles[e,f] [ms]	Weld Time Cycles[e,f] [ms]	Quench Time Cycles[e,f] [ms]	Temper Time Cycles[e,f] [ms]	Welding Current [Approx.] Weld Amps	Welding Current [Approx.] Temper Amps	Minimum Contacting Overlap mm [in]	Minimum Weld Spacing ℄ to ℄ mm [in]	Nugget Diameter mm [in]	Minimum Tension Shear Strength kN [lb]
0.81 [0.032]	16 [0.63]	152 [6]	7.56 [1700]	12.46 [2800]	17 [283]	13 [216]	0 [0]	13 [216]	6 500	4 400	11.1 [0.44]	19.0 [0.75]	4.06 [0.160]	5.34 [1 200]
1.57 [0.062]	22 [0.88]	203 [8]	11.56 [2600]	20.02 [4500]	43 [716]	35 [583]	2 [333]	46 [766]	8 300	5 650	16.0 [0.63]	31.8 [1.25]	6.86 [0.270]	16.01 [3 600]
2.36 [0.093]	22 [0.88]	203 [8]	15.47 [3500]	27.58 [6200]	69 [1150]	55 [916]	7 [116]	73 [1216]	10 000	7 000	19.0 [0.75]	38.1 [1.50]	8.31 [0.327]	26.69 [6 000]
3.18 [0.125]	22 [0.88]	203 [8]	19.13 [4300]	34.25 [7700]	91 [1516]	73 [1216]	13 [216]	99 [1650]	11 750	8 350	22.2 [0.87]	54.0 [2.13]	9.63 [0.379]	36.21 [8 140]
3.63 [0.143]	32 [1.25]	203 [8]	20.68 [4650]	37.37 [8400]	104 [1733]	83 [1383]	17 [283]	112 1867]	12 700	9 050	25.4 [1.00]	60.3 [2.37]	9.78 [0.385]	40.92 [9 200]
3.96 [0.156]	32 [1.25]	203 [8]	22.02 [4950]	39.14 [8800]	113 [1883]	89 [1483]	21 [350]	121 [2017]	13 600	9 700	31.8 [1.25]	69.8 [2.75]	10.74 [0.423]	44.93 [10 100]
4.78 [0.188]	38 [1.50]	203 [8]	24.91 [5600]	42.26 [9500]	128 [2133]	100 [1667]	30 [500]	145 [2417]	14 700	10 450	34.9 [1.37]	76.2 [3.00]	11.58 [0.456]	50.26 [11 300]

Note: The parameters shown represent a starting point from which a weld schedule can be established.
[a] Nominal chemical composition of nickel–chromium alloy X750 [UNS N07750], wt %: 73.0 Ni, 15.5 Cr, 6.75 Fe, 2.50 Ti, 0.85 Cb, 0.80 Al, 0.70 Mn, 0.05 Cu, 0.04 C, 0.030 Si, 0.007 S.
[b] Cycles per second or Hz can also be presented in ms [milliseconds].
[c] Electrode material: RWMA Class 2 or Class 3.
[d] Electrode widths are based on the following: ISO Standards 13, 16, 19, 22, 32, and 38 mm; RWMA Standards 0.48 (0.50), 0.63, 0.75, 0.88, 1.00, 1.25, and 1.50 in.
[e] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz multiply the weld times shown in cycles by 0.83 and round down to the nearest whole number.
[f] For DC welding equipment, lower current settings may be appropriate.

Table 26
Seam-Welding Parameters for Annealed Nickel–Chromium Alloy X750[a] on Single-Phase Equipment[b]



Sheet Thickness mm [in]	Electrode Wheel Width and Shape[c,d,e] W mm [in] Min.	E mm [in] Max.	Radius mm [in]	Net Electrode Force kN [lb]	On Time Cycles[f] [ms]	Off Time [Pressure Tight] Cycles[f] [ms]	Weld Speed mm/min [in/min]	Welds per meter [in]	Welding Current [Approx.] Amps	Minimum Contacting Overlap mm [in]
0.25 [0.010]	6 [0.25]	3.2 [0.13]	76 [3.0]	1.8 [400]	1 [16]	3 [50]	1140 [45]	790 [20]	3 600	4.8 [0.19]
0.38 [0.015]	6 [0.25]	3.2 [0.13]	76 [3.0]	3.1 [700]	2 [33]	4 [66]	910 [36]	670 [17]	3 900	6.4 [0.25]
0.53 [0.021]	10 [0.38]	5.6 [0.22]	76 [3.0]	6.2 [400]	3 [50]	6 [100]	760 [30]	550 [14]	8 000	7.9 [0.31]
0.79 [0.031]	10 [0.38]	4.8 [0.19]	76 [3.0]	10.2 [2300]	4 [66]	8 [133]	760 [30]	470 [12]	8 500	9.5 [0.37]
1.57 [0.062]	13 [0.50]	4.8 [0.19]	152 [6.0]	17.8 [4000]	8 [133]	16 [266]	300 [12]	390 [10]	10 300	9.5 [0.37]

Note: The parameters shown represent a starting point from which a weld schedule can be established.
[a] Nominal chemical composition of nickel–chromium alloy X750 [UNS N07750], wt %: 73.0 Ni, 15.5 Cr, 6.75 Fe, 2.50 Ti, 0.85 Cb, 0.80 Al, 0.70 Mn, 0.05 Cu, 0.04 C, 0.030 Si, 0.007 S.
[b] For DC welding equipment, lower current settings may be appropriate.
[c] Electrode material: RWMA Class 2 or Class 3.
[d] Class 2 preferred for 0.54, 0.38, and 0.53 mm [0.010, 0.015, and 0.021 in] thicknesses; for 0.79 and 1.57 mm [0.031 and 0.062 in] thicknesses, Class 2 or 3 is suitable.
[e] Electrode widths are based on the following: ISO Standards 6, 10, 13, 16, 19 and 22 mm; RWMA Standards 0.25, 0.38, 0.48(0.50), 0.63, 0.75, 0.88, and 1.00 in.
[f] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz multiply the weld times shown in cycles by 0.83 and round down to the nearest whole number.

4.7.6.1 Squeeze Time. This time includes allowances for delays in valve shifting, mechanical movement of the weld head to the work, the complete pressurization of the cylinder, and the bringing of the pieces to be welded into intimate contact. Inadequate squeeze time results in inconsistent weld quality.

4.7.6.2 Weld Time. Proper weld times are based upon current and electrode force values chosen for the materials being joined. Longer or shorter weld times may result in inconsistent weld quality.

4.7.6.3 Hold Time. The electrode provides a continued force to the weld nugget, and cools the workpiece as long as pressure is maintained. The number of cycles of hold time needed varies with material and thickness. Actual hold time is usually several cycles longer than the specified hold time because of mechanical delays.

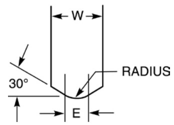
4.7.6.4 Heat and Cool Times (Seam Welding). If a slower welding speed is necessary, the cool time should be increased to maintain the same number of welds per mm [in], thus preventing an excessive heat input which may cause undue distortion of the work. The welds per mm are related to the welding speed, weld time, and cool time as shown by the following formula:

$$\text{SI units: Welds per mm} = \frac{60 \times \text{Line Frequency (cycles per second)}}{(\text{Heat Time} + \text{Cool Time}) \times \text{Welding Speed (mm/min)}}$$

$$\text{U.S. Customary units: Welds per inch} = \frac{60 \times \text{Line Frequency (cycles per second)}}{(\text{Heat Time} + \text{Cool Time}) \times \text{Welding Speed [in/min]}}$$

where the heat and cool times are in cycles and the welding speed is in mm per minute or in inch per minute.

Table 27
Seam-Welding Parameters for Annealed Nickel–Chromium Alloy X750[a] on Three-Phase Frequency Converter Machines

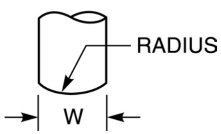


	Electrode Width and Shape[b,c]				Intermittent										
Sheet Thickness mm [in]	E mm [in] Max.	W mm [in] Min.	Radius mm [in]	Net Electrode Force kN [lb]	Weld Time Cycles[d] [ms]	Cool Time Cycles[d] [ms]	Pulses	Forge Time Cycles[d] [ms]	Motor On Time Cycles[d] [ms]	Continuous	Weld Speed [Approx.] mm/min [in/min]	Welds per meter [in]	Welding Current [Approx.] Amps	Nugget Width mm [in] L	Minimum Contacting Overlap mm [in]
0.64 [0.025]	5.6 [0.22]	10 [0.38]	76 [3.0]	5.34 [1200]	10 [166]	1 [16]	—	—	—	X	432 [17]	790 [20]	6 000	4.3 [0.17]	9.5 [0.37]
0.80 [0.031]	6.4 [0.25]	10 [0.38]	127 [5.0]	5.78 [1300]	12 [200]	2 [33]	—	—	—	X	381 [15]	710 [18]	6 500	5.6 [0.22]	7.9 [0.44]
1.09 [0.043]	6.4 [0.25]	13 [0.50]	127 [5.0]	7.56 [1700]	14 [233]	5 [83]	—	15 [250]	—	X	330 [13]	590 [15]	7 000	6.1 [0.24]	12.7 [0.50]
1.57 [0.062]	7.9 [0.44]	13 [0.50]	203 [8.0]	11.12 [2500]	20 [333]	1 [16]	1	15 [250]	15 [250]	—	152 [6]	470 [12]	8 500	6.9 [0.27]	15.9 [0.63]
2.36 [0.093]	7.9 [0.44]	19 [0.75]	254 [10.0]	15.57 [3000]	15 [250]	1 [16]	2	20 [333]	15 [250]	—	140 [5.5]	430 [11]	11 000	9.1 [0.36]	19.0 [0.75]
3.18 [0.125]	12.7 [0.50]	19 [0.75]	254 [10.0]	20.02 [4500]	20 [333]	1 [16]	2	—	15 [250]	—	114 [4.5]	430 [11]	13 000	10.7 [0.42]	22.2 [0.87]

[a] Nominal chemical composition of nickel–chromium alloy X750 (UNS N07750), wt %: 73.0 Ni, 15.5 Cr, 6.75 Fe, 2.50 Ti, 0.85 Cb, 0.80 Al, 0.70 Mn, 0.05 Cu, 0.04 C, 0.030 Si, 0.007 S.
[b] Electrode material: Class 2 or Class 3.
[c] Electrode widths are based on the following: ISO Standards 10, 13, 16, 19, and 22 mm; RWMA Standards 0.38, 0.48 (0.50), 0.63, 0.75, 0.88, and 1.00 in.
[d] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz multiply the weld times shown in cycles by 0.83 and round down to the nearest whole number.

Notes:
1. The parameters shown represent a starting point from which a weld schedule can be established.
2. Intermittent welding motion recommended for thicknesses greater than 1.27 mm (0.050 in) to produce defect-free welds.
3. Weld time based on 20-cycle machine. For machines with limited on-time, heat and cool times should be adjusted accordingly.

Table 28
Roll-Spot-Welding Parameters for Annealed Nickel–Chromium Alloy X750[a] on Three-Phase Dry Disk Rectifier Machines

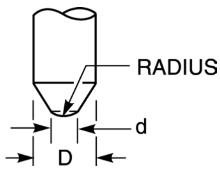


	Electrode Wheel Width and Shape[b,c,d]		Net Electrode Force		Intermittent Drive				Welding Current [Approx.]					
Sheet Thickness mm [in]	W mm [in] Min.	Radius mm [in]	Weld kN [lb]	Forge kN [lb]	Forge Delay Time Cycles[e,f] [ms]	Weld Time Cycles[e,f,] [ms]	Quench Time Cycles[e,f] [ms]	Temper Time Cycles[e,f] [ms]	Weld Amps	Temper Amps	Welds per meter [in]	Weld Speed[g] mm/min [in/min]	Nugget Width mm [in]	Minimum Contacting Overlap mm [in]
0.81 [0.032]	10 [0.38]	76 [3.0]	7.56 [1700]	12.46 [2800]	17 [283]	13 [216]	0 [0]	13 [216]	5 150	4 200	472 [12.0]	127 [5.0]	4.83 [0.190]	11.1 [0.44]
1.57 [0.062]	13 [0.50]	152 [6.0]	11.56 [2600]	20.02 [4500]	43 [716]	35 [583]	3 [50]	45 [750]	5 350	5 070	394 [10.0]	76 [3.0]	6.50 [0.256]	16.0 [0.63]
2.36 [0.093]	19 [0.75]	203 [8.0]	15.57 [3500]	27.58 [6200]	69 [1150]	55 [916]	7 [116]	73 [1216]	10 000	5 200	354 [9.0]	61 [2.4]	8.00 [0.315]	19.0 [0.75]
3.18 [0.125]	19 [0.75]	203 [8.0]	19.13 [4300]	34.25 [7700]	91 [1516]	73 [1216]	13 [216]	98 [1633]	11 750	5 350	335 [8.5]	53 [2.1]	9.32 [0.367]	19.0 [0.75]
3.63 [0.143]	19 [0.75]	254 [10.0]	20.68 [4650]	36.92 [8300]	103 1717]	82 [1366]	17 [283]	112 [1867]	12 500	9 000	315 [8.0]	46 [1.8]	9.91 [0.390]	22.2 [0.87]
3.96 [0.156]	19 [0.75]	254 [10.0]	21.80 [4900]	38.92 [8750]	110 [1833]	86 [1433]	21 [350]	120 [2000]	13 200	9 250	295 [7.5]	43 [1.7]	10.29 [0.405]	25.4 [1.00]
4.76 [0.187]	19 [0.75]	254 [10.0]	24.91 [5600]	42.56 [9500]	128 [2133]	100 [1667]	30 [500]	187 [3117]	14 750	10 300	236 [6.0]	38 [1.5]	11.05 [0.435]	25.4 [1.00]

Note: The parameters shown represent a starting point from which a weld schedule can be established.
[a] Nominal chemical composition of nickel–chromium alloy X750 (UNS N07750), wt %: 73.0 Ni, 15.5 Cr, 6.75 Fe, 2.50 Ti, 0.85 Cb, 0.80 Al, 0.70 Mn, 0.05 Cu, 0.04 C, 0.030 Si, 0.007 S.
[b] Electrode material: RWMA Class 2 or Class 3.
[c] Where practical, both electrode wheels should be of same diameter and radius. When geometry of parts makes it impossible to use wheels of same diameter, it may be necessary to use different radii. This may also be necessary when welding unequal thickness material. Electrode material generally used is RWMA Class 3 for the longest wheel life, but Class 2 is often used as one of the wheels in order to effect a heat balance.
[d] Electrode widths are based on the following: ISO Standards 10, 13, 16, 19, and 22 mm; RWMA Standards 0.38, 0.48 (0.50), 0.63, 0.75, 0.88, and 1.00 in.
[e] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz multiply the weld times shown in cycles by 0.83 and round down to the nearest whole number.
[f] For DC welding equipment, lower current settings may be appropriate.
[g] The weld speed is based on using 20 cycles hold time and 15 cycles index time with the given spots per meter (inch).

Table 29
Spot-Welding Parameters for Annealed Nickel on Single-Phase Equipment[a]

Electrode Diameter and Shape[b,c,d]



Sheet Thickness mm [in]	d mm [in] Max.	D mm [in] Min.	Net Electrode Force kN [lb]	Weld Time[e] Cycles [ms]	Welding Current [Approx.] Amps	Minimum Contacting Overlap mm [in] L	Minimum Weld Spacing mm [in]	Nugget Diameter mm [in]	Minimum Shear Strength kN [lb]
0.13 [0.005] to:									
0.13 [0.005]	4.0 [0.16]	6 [0.25]	0.44 [100]	3 [50]	7 100	6.4 [0.25]	9.5 [0.37]	2.5 [0.10]	0.13 [30]
0.25 [0.010]	4.0 [0.16]	6 [0.25]	0.44 [100]	3 [50]	7 400	6.4 [0.25]	7.9 [0.31]	2.5 [0.10]	0.16 [36]
0.38 [0.015]	4.0 [0.16]	6 [0.25]	0.49 [110]	3 [50]	7 500	6.4 [0.25]	7.9 [0.31]	2.5 [0.10]	0.18 [40]
0.53 [0.021]	4.0 [0.16]	6 [0.25]	0.49 [110]	3 [50]	7 800	6.4 [0.25]	12.7 [0.50]	2.5 [0.10]	0.20 [45]
0.78 [0.031]	4.0 [0.16]	6 [0.25]	0.49 [110]	3 [50]	8 000	6.4 [0.25]	12.7 [0.50]	2.5 [0.10]	0.22 [50]
1.6 [0.063]	4.0 [0.16]	6 [0.25]	0.52 [120]	3 [50]	8 100	6.4 [0.25]	9.5 [0.37]	2.5 [0.10]	0.22 [50]
2.4 [0.093]	4.0 [0.16]	6 [0.25]	0.52 [120]	3 [50]	8 150	6.4 [0.25]	16.0 [0.63]	2.5 [0.10]	0.22 [50]
3.2 [0.125]	4.0 [0.16]	6 [0.25]	0.52 [120]	3 [50]	8 200	6.4 [0.25]	16.0 [0.63]	2.5 [0.10]	0.24 [55]
0.25 [0.010] to:									
0.25 [0.010]	4.8 [0.19]	6 [0.25]	0.58 [130]	3 [50]	11 800	6.4 [0.25]	9.5 [0.37]	3.0 [0.12]	0.60 [135]
0.38 [0.015]	4.0 [0.16]	6 [0.25]	0.58 [130]	3 [50]	11 900	6.4 [0.25]	9.5 [0.37]	3.0 [0.12]	0.64 [145]
0.53 [0.021]	4.0 [0.16]	6 [0.25]	0.58 [130]	3 [50]	12 000	6.4 [0.25]	7.9 [0.31]	3.0 [0.12]	0.67 [150]
0.78 [0.031]	4.0 [0.16]	6 [0.25]	0.58 [130]	3 [50]	12 200	6.4 [0.25]	7.9 [0.31]	3.0 [0.12]	0.71 [160]
1.6 [0.063]	4.0 [0.16]	6 [0.25]	0.62 [140]	3 [50]	12 300	6.4 [0.25]	12.7 [0.50]	3.0 [0.12]	0.82 [185]
2.4 [0.093]	4.0 [0.16]	6 [0.25]	0.62 [140]	3 [50]	12 300	6.4 [0.25]	16.0 [0.63]	3.0 [0.12]	0.86 [190]
3.2 [0.125]	4.0 [0.16]	6 [0.25]	0.67 [150]	3 [50]	12 500	6.4 [0.25]	16.0 [0.63]	3.0 [0.12]	0.93 [210]
0.38 [0.015] to:									
0.38 [0.015]	4.8 [0.19]	6 [0.25]	11.1 [250]	3 [50]	12 300	6.4 [0.25]	7.9 [0.31]	3.0 [0.12]	0.80 [180]
0.53 [0.021]	4.8 [0.19]	6 [0.25]	11.1 [250]	3 [50]	12 500	6.4 [0.25]	12.7 [0.50]	3.3 [0.13]	1.11 [250]
0.78 [0.031]	4.8 [0.19]	6 [0.25]	11.1 [250]	3 [50]	12 600	6.4 [0.25]	12.7 [0.50]	3.3 [0.13]	1.25 [280]
1.6 [0.063]	4.8 [0.19]	6 [0.25]	1.16 [260]	3 [50]	12 800	6.4 [0.25]	14.3 [0.56]	3.3 [0.13]	1.33 [300]
2.4 [0.093]	4.8 [0.19]	16 [0.63]	1.16 [260]	3 [50]	13 000	6.4 [0.25]	16.0 [0.63]	3.3 [0.13]	1.56 [350]
3.2 [0.125]	4.8 [0.19]	16 [0.63]	1.16 [260]	3 [50]	13 100	6.4 [0.25]	16.0 [0.63]	3.3 [0.13]	1.38 [310]
0.53 [0.021] to:									
0.53 [0.021]	4.0 [0.16]	6 [0.25]	1.65 [370]	4 [66]	7 800	7.9 [0.31]	14.3 [0.56]	3.0 [0.12]	1.47 [330]
0.78 [0.031]	4.0 [0.16]	6 [0.25]	1.65 [370]	4 [66]	8 200	7.9 [0.31]	16.0 [0.63]	3.0 [0.12]	1.65 [370]
1.6 [0.063]	4.0 [0.16]	6 [0.25]	1.65 [370]	4 [66]	8 600	7.9 [0.31]	16.0 [0.63]	3.0 [0.12]	1.76 [400]
2.4 [0.093]	4.0 [0.16]	16 [0.63]	1.69 [380]	4 [66]	8 800	7.9 [0.31]	17.5 [0.69]	3.0 [0.12]	1.91 [430]
3.2 [0.125]	4.0 [0.16]	16 [0.63]	1.69 [380]	4 [66]	9 000	7.9 [0.31]	19.0 [0.75]	3.3 [0.13]	2.00 [450]
0.78 [0.031] to:									
0.78 [0.031]	4.8 [0.19]	6 [0.25]	4.00 [900]	4 [66]	15 400	9.5 [0.37]	22.2 [0.87]	4.6 [0.18]	3.38 [760]
1.6 [0.063]	4.8 [0.19]	6 [0.25]	4.00 [900]	4 [66]	15 200	9.5 [0.37]	22.2 [0.87]	4.3 [0.17]	3.43 [770]
2.4 [0.093]	4.8 [0.19]	6 [0.25]	4.00 [900]	6 [100]	13 500	9.5 [0.37]	25.4 [1.00]	4.6 [0.18]	3.74 [840]
3.2 [0.125]	4.8 [0.19]	16 [0.63]	4.36 [980]	6 [100]	14 200	9.5 [0.37]	25.4 [1.00]	4.6 [0.18]	4.14 [930]
1.6 [0.063] to:									
1.6 [0.063]	6.4 [0.25]	6 [0.25]	7.65 [1720]	6 [100]	21 600	16.0 [0.63]	38.1 [1.50]	6.4 [0.25]	10.78 [2400]
2.4 [0.093]	6.4 [0.25]	6 [0.25]	8.01 [1800]	8 [133]	20 000	16.0 [0.63]	41.3 [1.63]	6.4 [0.25]	11.34 [2550]
3.2 [0.125]	6.4 [0.25]	6 [0.25]	8.01 [1800]	10 [166]	21 000	16.0 [0.63]	44.5 [1.75]	6.4 [0.25]	11.79 [2650]
2.4 [0.093] to:									
2.4 [0.093]	7.9 [0.31]	10 [0.37]	10.23 [2300]	12 [200]	26 400	19.0 [0.75]	47.6 [1.87]	7.9 [0.31]	16.01 [3600]
3.2 [0.125]	7.9 [0.31]	10 [0.37]	10.23 [2300]	20 [333]	25 400	19.0 [0.75]	50.8 [2.00]	7.9 [0.31]	16.46 [3700]
3.2 [0.125] to:									
3.2 [0.125]	9.5 [0.37]	10 [0.37]	14.68 [3300]	20 [333]	31 000	22.2 [0.87]	57.2 [2.25]	9.5 [0.37]	24.91 [5600]

Note: The parameters shown represent a starting point from which a weld schedule can be established.

[a] For DC welding equipment, lower current settings may be appropriate.
[b] Electrode shape may be flat rather than domed; in which case the shear strengths and nugget diameters will be higher and larger than shown in the table.
[c] Electrode material: RWMA Class 1 or Class 2.
[d] Electrode widths are based on the following: ISO Standards 6, 10, 13, 16, 19, and 22 mm; RWMA Standards 0.25, 0.38, 0.48 (0.50), 0.63, 0.75, 0.88, and 1.00 in.
[e] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz multiply the weld times shown in cycles by 0.83 and round down to the nearest whole number.

Table 30
Spot-Welding Parameters for Nickel–Iron–Chromium Alloys[a b]

Sheet Thickness mm [in]	Electrodes: Material	Electrodes: Face Diameter mm [in]	Electrodes: Tip Contour	Weld Force kN [lb]	Forge Force kN [lb]	Weld Time Cycles[c] [ms]: Heat	Weld Time Cycles[c] [ms]: Cool	Impulses	Welding Current [Approx.] Amps	Average Shear Strength kN [lb]	Average Tensile Strength kN [lb]
0.76 [0.030]	RWMA Class 3	6.4 [0.25]	Flat	4.0 [900]	11.1 [2500]	8 [133]	2 [33]	2	18 900	6.13 [1380]	3.88 [872]
1.60 [0.063]	RWMA Class 3	7.9 [0.31]	Flat	11.1 [2500]	17.8 [4000]	10 [166]	2 [33]	10	21 700	14.62 [3290]	8.68 [1950]
2.39 [0.094]	RWMA Class 2	9.5 [0.37]	Flat	19.6 [4400]	33.4 [7500]	9 [150]	2 [33]	4	30 500	21.42 [4800]	18.99 [4270]

Note: The parameters shown represent a starting point from which a weld schedule can be established.
[a] Nominal chemical composition of nickel–iron–chromium alloys (UNS N06002), wt %: 47.5 Ni, 21.7 Cr, 18.5 Fe, 9.0 Mo, 1.5 Co, 0.1 C.
[b] For DC welding equipment, lower current settings may be appropriate.
[c] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz multiply the weld times shown in cycles by 0.83 and round down to the nearest whole number.

Table 31
Seam-Welding Parameters for Nickel–Iron–Chromium Alloys[a,b]

Sheet Thickness mm [in]	Electrode Wheel Face Width[c] [Flat Face] mm [in]	Net Electrode Force kN [lb]: Weld	Net Electrode Force kN [lb]: Forge	Weld Time[d]: Heat Cycles [ms]	Weld Time[d]: Cool Cycles [ms]	Weld Time[d]: Impulses	Weld Time[d]: Forge Cycles [ms]	Welding Current [Approx.] Amps	Welding Speed Welds per m [in]
0.76 [0.030]	4.8 [0.19]	6.67 [1.50]	None	10 [166]	2 [33]	1	None	20 250	550 [14]
1.60 [0.063]	7.9 [0.31]	8.90 [2.00]	17.79 [4.00]	10 [166]	2 [33]	8	15 [250]	21 500	394 [10]
2.39 [0.094]	9.5 [0.37]	20.02 [4.50]	20.02 [4.50]	10 [166]	2 [33]	4	25 [416]	33 000	315 [8]

Note: The parameters shown represent a starting point from which a weld schedule can be established.
[a] Nominal chemical composition of nickel–Iron–chromium alloys (UNS N06002), wt %: 47.5 Ni, 21.7 Cr, 18.5 Fe, 9.0 Mo, 15 Co, 0.1 C.
[b] For DC welding equipment, lower current settings may be appropriate.
[c] Electrode material: RWMA Class.
[d] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz multiply the weld times shown in cycles by 0.83 and round down to the nearest whole number.

Table 32
Seam-Welding Parameters for Cobalt–Chromium–Nickel Alloys[a,b]

Sheet Thickness mm [in]	Electrode[c]: Diameter mm [in]	Electrode[c]: Tip Contour	Force kN [lb]: Weld	Force kN [lb]: Forge	Weld Time[d]: Heat Cycles [ms]	Weld Time[d]: Cool Cycles [ms]	Weld Time[d]: Impulses	Weld Time[d]: Forge Cycles [ms]	Welding Current [Approx.] Amps	Average Shear Strength kPa [ksi]	Average Tensile Strength kPa [ksi]
0.76 [0.030]	4.8 [0.19]	Flat	3.34 [750]	7.12 [1600]	10 [166]	0.5 [8]	1	45 [750]	13 650	8.915 [1.293]	5.65 [0.82]
1.60 [0.063]	7.9 [0.31]	Flat	8.90 [2000]	17.80 [4000]	10 [166]	2.5 [41]	4	50 [833]	15 000	27.58 [4.000]	20.68 [3.00]
2.39 [0.094]	12.7 [0.50]	Flat	13.34 [3000]	37.81 [8500]	20 [333]	0.5 [8]	8	200 [3334]	19 800	55.71 [8.080]	39.51 [5.73]

Note: The parameters shown represent a starting point from which a weld schedule can be established.
[a] Nominal chemical composition of cobalt–chromium–nickel alloys [UNS R30605), wt %: 52 Co, 20 Cr, 15 W, 10 Ni, 1.5 Mn, 0.1 C.
[b] For DC welding equipment, lower current settings may be appropriate.
[c] Electrode material: RWMA Class 3.
[d] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz multiply the weld times shown in cycles by 0.83 and round down to the nearest whole number.

Table 33
Spot-Welding Parameters for Various Copper Alloys

Alloy	Weld Time Cycles[a,b] [ms]	Net Electrode Force kN [lb]	Welding Current Amps
Muntz metal	4 [66]	1.78 [400]	21 000
High brass	4 [66]	1.78 [400]	21 000
Cartridge brass	4 [66]	1.78 [400]	21 000
Low brass	6 [100]	1.78 [400]	21 000
Red brass	6 [100]	1.78 [400]	21 000
Manganese red brass	6 [100]	1.78 [400]	21 000
Aluminum bronze	4 [66]	1.78 [400]	21 000
Silicon brass	6 [100]	2.27 [510]	21 000
Silicon bronze	6 [100]	1.78 [400]	21 000
Phosphor bronze	6 [100]	2.27 [510]	21 000
Nickel-aluminum bronze	6 [100]	1.78 [400]	21 000
Nickel-aluminum bronze [precipitation hardenable]	4 [66]	2.27 [510]	21 000

[a] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz multiply the weld times shown in cycles by 0.83 and round down to the nearest whole number.
[b] For DC welding equipment, lower current settings may be appropriate.

Notes:
1. The parameters shown represent a starting point from which a weld schedule can be established.
2. Sheet thickness: 0.91 mm [0.036 in].
3. Electrode: RWMA Class 1, 6 mm [0.25 in] face diameter (flat tip), 30 degrees bevel.

Source: Resistance Welding Theory and Use, American Welding Society, Miami, Florida, 1956.

Table 34
Spot-Welding Parameters for Titanium Alloy 6%Al–4% V

Sheet Thickness mm [in]	Net Electrode Force kN [lb]	Weld Time Cycles[a,b] [ms]	Welding Current Amps	Contacting Overlap mm [in]	Nugget Diameter mm [in]	Weld Penetration %	Shear Strength kN [lb]	Cross-Tension Strength kN [lb]
0.89 [0.035]	2.67 [600]	7 [116]	5 500	12.7 [0.50]	—	—	7.65 [1720]	2.67 [600]
1.57 [0.062]	6.67 [1500]	10 [166]	10 600	15.9 [0.63]	8.4 [0.33]	87.3	22.22 [5000]	4.45 [1000]
1.78 [0.070]	7.56 [1700]	12 [200]	11 500	15.9 [0.63]	—	—	28.25 [6350]	8.23 [1850]
2.36 [0.093]	10.68 [2400]	16 [266]	12 500	19.0 [0.75]	—	—	37.37 [8400]	9.34 [2100]

[a] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz multiply the weld times shown in cycles by 0.83 and round down to the nearest whole number.
[b] For DC welding equipment, lower current settings may be appropriate.

Notes:
1. The parameters shown represent a starting point from which a weld schedule can be established.
2. Electrode: RWMA Class 2, 16 mm [0.63 in] dia. shank, 76 mm [3.0 in] tip radius.
3. Squeeze time, cycles: 60.
4. Hold time, cycles: 60.

Source: Welding and Process Manual-Titanium, *Welding Engineer*, April 1967.

4.7.6.5 Off Time. This variable is generally used when the welding cycle is repetitive.

4.7.7 Weld Current. The values shown in the tables are approximate and are intended to help calculate and specify the capacity of welding machines. When the electrode force has been established, the current may be increased to the point where metal expulsion occurs and then reduced to just below this point. Optimum strengths, nugget diameters, and penetration values may be obtained by this method.

4.7.7.1 Weld Schedule Options. Some welding conditions may benefit from weld schedule options. These include preheat, upslope, pulsation, postheat, downslope, and heat steppers. These options adjust the welding current before, during, and after welding. They may be used alone or in combination with one another to provide various benefits such as annealing, tempering, increased tip dressing intervals, longer electrode life, and reduced power consumption.

4.7.8 Minimum Contacting Overlap. These values indicate the minimum overlap to obtain satisfactory welds. It is important to avoid using overlap below these recommended values; otherwise, expulsion of metal, distortion of the lapping sheets, or edge welds may occur, and the weld may have low strength and contain porosity and cracking.

4.7.9 Minimum Spot-Weld Spacing. The weld spacings specified are measured from weld center to weld center. Values less than those indicated create increased shunting currents. This condition requires compensation unless other measures are used to compensate for current shuntings.

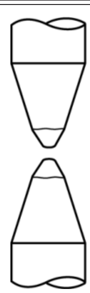
4.7.10 Nugget (Fusion Zone) Diameter or Width. These values may be used to establish nugget diameter (spot welds) or width (seam welds).

4.7.11 Minimum Shear and Tensile Strengths. Tension-shear and cross-tension tests are acceptable methods of checking of spot welds.

It should be recognized that variations in individual weld strengths exist. If weld strength is used to determine an acceptable machine setting, it should be above a minimum acceptable value.

4.7.12 Spot-Welding Various Thickness Combinations and Arrangements. The welding parameters used are normally determined by deciding which of the sheet thicknesses in a particular combination should determine or "govern" the weld schedule. Table 36 shows the guidelines that should generally be followed in setting up welding parameters to join various thickness combinations and arrangements of uncoated and coated carbon and low-alloy steels. In using this table, first refer to the left column, "Metal Combinations and Arrangements", to identify the applicable metal combination

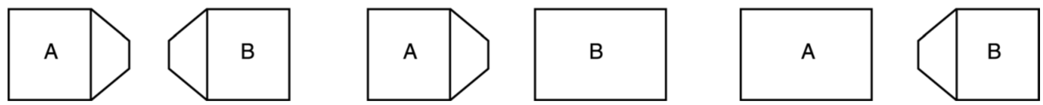
Table 35
Variation of Current Density and Unit Force Due to Lack of Electrode Tip Maintenance

1 Tip Area 400% Too Small	2[a] Proper Tip Area	3 Tip Area 56% Too Large	4 Tip Area 125% Too Large	5 Tip Area 300% Too Large
				
0.079 cm^2 [0.0123 $in.^2$]	0.317 cm^2 [0.0491 $in.^2$]	0.495 cm^2 [0.0767 $in.^2$]	0.713 cm^2 [0.1105 $in.^2$]	0.713 cm^2 [0.1105 $in.^2$]
At Diameter 3.18 mm [0.125 in.]	At Diameter 6.35 [0.250 in.]	At Diameter 7.94 [0.313 in.]	At Diameter 9.52 mm [0.375 in.]	At Diameter 9.52 mm [0.375 in.]
Unit Force 411 MPa [59 000 psi]	Unit Force 103 MPa [15 000 psi]	Unit Force 65 MPa [9 500 psi]	Unit Force 45 MPa [6 500 psi]	Unit Force 26 MPa [3 710 psi]
Current Density 123 690 A/cm^2 [798 880 A/$in.^2$]	Current Density 31 000 A/cm^2 [200 000 A/$in.^2$]	Current Density 19 810 A/cm^2 [127 800 A/$in.^2$]	Current Density 13 640 A/cm^2 [88 000 A/$in.^2$]	Current Density 7 730 A/cm^2 [49 900 A/$in.^2$]
Result There is 400% too much force and current. Severe indentation and expulsion from high current density.	Result Good Spot Weld Ideal Setup	Result Only 64% of the required force and current.	Result Only 44% of the required force and current.	Result Only 25% of the required force and current.
		Weak Spot Weld	Stick Weld	No Weld At All

[a] Example 2 shows the correct tip size for application requiring a welding force of 3250 N [730 lb] and a welding current of 9800 A. Thus a 6.35 mm [0.250 in] diameter electrode tip will produce a unit force of 103 MPa [1500 psi] and a current density of 3100 A/cm^2 [200 000 A/in^2].

Table 36
Spot-Welding Parameters for Various Thickness Combinations and Arrangements of Uncoated and Coated-Carbon and Low-Alloy Steels

Electrode Arrangement[a,b,c]



Metal Thickness Combinations[d] and Arrangements		1				2				3			
		Tip Dia. A	Tip Dia. B	Weld Schedule	Max. Thick Ratio	Tip Dia. A	Tip Dia. B	Weld Schedule	Max. Thick Ratio	Tip Dia. A	Tip Dia. B	Weld Schedule	Max. Thick Ratio
X=Y	X Y	X	X	X	—	X	Flat	X+10%	—	Flat	Y	Y+10%	—
X<Y	X Y	X	X	X	X/Y=1/4	X	Flat	X+10%	X/Y=1/4	Flat	Y	Y+10%	X/Y=1/4
X=Y=Z	X Y Z	X	X	X+10%	—	X	Flat	X+15%	—	Flat	X	X+15%	—
Y<X Y<Z X<Z	X Y Z	X	X	X+10%	X/Z=1/2.5	X	Flat	X+15%	X/Z=1/2.5	Flat	Z	Z+15%	X/Z=1/2.5
X<Y Y>Z X<Z	X Y Z	Z	Z	Z+10%	X/Z=1/2.5	Z	Flat	Z+15%	X/Z=1/2.5	Flat	Z	X+20%	X/Z=1/2
X<Y<Z	X Y Z	Y	Y	Y+10%	X/Z=1/2.5	Z	Flat	Z+15%	X/Z=1/2.5	Flat	Z	Y+20%	X/Z=1/2
X>Y X=Z	X Y Z	X	X	X+10%	X/Y=1/4	X	Flat	X+10%	X/Y=1/4	Flat	X	X+10%	X/Y=1/4
X<Y X=Z	X Y Z	X	X	X+10%	X/Y=1/3	X	Flat	X+20%	X/Y=1/2.5	Flat	X	X+20%	X/Y=1/2.5
X<Y Y=Z	X Y Z	Z	Z	Z+10%	X/Z=1/2.5	Z	Flat	Z+10%	X/Z=1/2.5	Flat	Z	Z+20%	X/Z=1/2
X=Y X<Z	X Y Z	X	X	X+15%	X/Z=1/2.5	X	Flat	X+20%	X/Z=1/2.5	Flat	Z	Z+20%	X/Z=1/2

[a] Electrode arrangements 2 and 3 with flat electrodes may not provide satisfactory welds through all three sheets when welding galvanized steel.
[b] Where indicated in the weld schedule boxes above, add the indicated percent to weld current and weld force as shown in Tables 1, 2, 4, 5, 6, 7, 9, 10, and 11.
[c] Tip size and weld schedules are based on metal thickness column, as shown in box.
[d] X, Y, and Z are thicknesses.

arrangement. Next, select the desired electrode arrangement from across the top of the Table, and locate the box in that column that meets the specific combination. The letters in the boxes refer to the electrode diameters (A and B) and weld schedule to be used in a particular combination. These values are determined by finding the welding parameters recommended for the actual X, Y, Z metal sheet thickness values shown in Tables 1 through 7. Note that these recommended parameters apply only to set-ups with less than the "Maximum Thickness Ratio" as shown for each combination, and a change in electrode configuration would be required for ratios greater than these shown. It is also recommended that, for three sheet combinations, the minimum electrode spacing be increased by 30 percent above that normally used for two sheet combinations. For all applicable welding characteristics, the thinner layer of each faying surface governs.

4.8 Weld Discrepancies and Causes. Effective problem solving or troubleshooting in resistance welding requires an understanding of the welding process as well as knowledge of weld discrepancies and their causes. Generally, the solution becomes obvious once the cause is determined. The acceptability of a discrepancy depends on the specific application. The following is a general discussion of weld discrepancies and their causes.

Causes of spot, seam, and projection weld discrepancies can be divided into welding-equipment related and process-application related:

(1) Welding-Equipment Related:

(a) Welding machine:
- Improper machine type
- Improper kVA rating
- Inadequate range of adjustment of current or force
- Improper fixture design
- Excessive friction or inertia in the movable ram
- Electrode tip skidding
- Transformer saturation
- Broken leads of primary and secondary electrical circuits
- Excessive oxide build-up on contact surfaces of secondary circuit
- Line voltage variations
- Inadequate power supply cooling
- Machine mechanical and electrical repeatability

(b) Electrode:
- Deformed or worn electrodes that reduce the current density at the electrode-to-work interface
- Poor maintenance or misalignment
- Incorrect face shape or geometry
- Incorrect alloy
- Inadequate water cooling

(c) Welding Control:
- Incomplete function—one or more of the following may be required: pulsation, preheat, forge, quench, temper, current downslope, current upslope, etc.
- Repeatability
- Improper settings

(2) Process Application Related:

(a) Joint Configuration
- Poor part fit-up
- Poor part design
- Inadequate joint overlap
- Poor joint accessibility

(b) Surface Condition:
- Poor or inconsistent surface finish
- Contaminated surfaces
- High electrical resistance coating on surfaces to be welded

(c) Shunting of the welding current:
- Through previous welds
- Through the part itself
- Through fixturing or tooling

(d) Weld Parameters:
- Incorrect welding process
- Improper welding schedule

- Improper projection size or location
- Attempting to weld too many widely spaced projections at once

The following are various problems that occur in spot, seam, and projection welding, and their possible causes. It is assumed that the machine is functioning properly and that the metal to be welded is resistance weldable.

(1) Expulsion or Porosity at Weld Interface:
- Contaminated surfaces (drawing compound or paint)
- Poor part fit-up
- Inadequate joint overlap
- Electrode force too low
- Weld current too high
- Weld time too long
- Squeeze time too short
- Poor electrode follow-up
- Improper current pulse shape
- Current upslope too fast

(2) Expulsion at Electrode-to-Work Interface:
- Contaminated surfaces (drawing compound or paint)
- Electrode tip pick-up
- Squeeze time too short
- Welding current too high
- Electrodes not properly contacting the work
- Electrode misalignment
- Electrode force too low
- Incorrect electrode alloy

(3) Undersized Weld or Inadequate Penetration:
- Weld time too short
- Welding current too low
- Electrode force too high or too low
- Improper electrode shape
- Improper heat balance caused by dissimilar thickness or metal combination
- Projection size too small
- Insufficient weld spacing
- Shunting of welding current through welding fixture
- Improper coating and base-metal combination
- Projection spacing too large
- Excessive line voltage fluctuation
- Mushroomed or deformed electrodes

(4) Excessive Surface Indentation or Marking:
- Electrode force too high or too low
- Electrode contour too sharp or face too small
- Misaligned electrodes
- Poor part fit-up
- Weld time too long
- Weld current too high

(5) Cracks in the Weld:
- Hold time too short or too long
- Electrode force too low
- Forging force applied too late
- Improper electrode follow-up
- Improper electrode shape
- Current decay or downslope not used
- Surface contamination

(6) Displaced Weld Nugget with Inadequate Weld Penetration in One Sheet:
- Improper heat balance caused by dissimilar thicknesses or metals
- Improper electrode shape when welding dissimilar thicknesses or dissimilar metals
- Misaligned electrodes
- Poor part fit-up
- Improper combination of electrode materials

(7) Excessive Warpage in Welded Assembly:
- Weld time too long
- Too much heat or distortion by close proximity welds
- Inadequate electrode cooling
- Improper weld sequence
- Poor part fit-up
- Excessive constraint of the hot weldment within the weld fixture
- Excessive heat from poor fixturing and welds that are too close to each other

(8) Inadequate or Uneven Set-Down or Upset of Projection Welds:
- Electrode force too low
- Excessive welding machine deflection
- Improper tooling
- Weld time too short
- Weld current too low
- Improper projection design
- Too many projections per electrode
- Electrode misalignment
- Poor electrode follow-up

(9) Excessive Sheet Separation:
- Electrode shape too sharp
- Weld force too high or too low
- Excessive weld current
- Improper part fit-up
- Inadequate weld force

(10) Electrode Mushrooming:
- Excessive number of welds between electrode dressing or replacement
- Weld current too high
- Weld time too long
- Electrode force too high or too low
- Inadequate electrode cooling
- Electrodes too small for thickness being welded
- Improper electrode material

(11) Electrode Sticking:
- Weld current too high
- Weld time too long
- Electrode force too high or too low
- Inadequate electrode cooling
- Electrodes too small for thickness being welded
- Improper electrode material
- Surface contamination

4.9 Weld Quality and Mechanical Property Tests

4.9.1 Introduction. The manufacturer should establish and implement a systematic quality program as specified in American Society of Quality Control (ASQC) Quality Systems and Management documents, or other appropriate standards or specifications. Manufacturer standards and specifications should include standards and specifications, a quantitative definition for weld quality, a procedure for determining if weld quality standards are being met, and a procedure to restore weld quality standards when such quality standards are not being met.

If the quality program involves testing of welded specimens which are welded coupons instead of actual welded parts, these specimens should be representative of the production parts they represent with respect to material, size, shape, thickness combination, surface condition or preparation, contact overlap, and weld spacing (spot and projection welds) or welds per mm [inch] (seam welds). A spot- or projection-welded test specimen may require only one weld if there is no significant shunt current effect caused by adjacent welds during welding of the actual parts.

The common weld quality and mechanical property tests for resistance spot and seam welds are described in the following subclauses.

4.9.2 Destructive Weld Quality Tests

4.9.2.1 Metallographic Test. A metallographic test is used to determine the weld nugget diameter, penetration, surface indentation, and sheet separation. It is also used to detect cracks, porosity, nonmetallic inclusions, and metal expulsion.

In this test, weld sections are cut and polished to the weld centerline, chemically etched[1] to reveal the microstructure, and then optically examined. For large welds, the weld nugget diameter and penetration may be measured using dividers or a scale. For small welds, these values should be determined using a microscope.

4.9.2.2 Peel Test. The peel test is used to determine the weld button diameter and weld fracture mode of spot and projection welds.

The test consists of peeling apart a test specimen as shown in Figure 4.

The specimen contact overlap should be large enough to allow the specimen to be gripped and peeled apart. To determine the current shunting effect, several spot welds can be made using the desired spacing. The sample is cut transversely before peeling starts, using the last weld made as the test sample. Three welds are recommended for this adaptation as shown in Figure 5.

The size of the weld button can be measured, as shown in Figure 6, to determine if it meets the minimum requirements.

Resistance spot welds can exhibit several different weld fracture modes. There are two different failure modes generally observed, namely, "interfacial fractures" and "full button pull out" (See Figure 7). In the interfacial fracture, the weld fails at the interface of the two sheets, leaving half of the weld nugget in one sheet and half in the other. In the full button pull out, fracture occurs in the base metal or in the weld heat-affected zone at the perimeter of the weld. In this failure mode, the weld nugget is completely torn from one of the sheets with the weld remaining intact. It is also possible to get a combination of the two failure modes in which a portion of the nugget is pulled out of one of the sheets and the rest of the nugget shears at the interface.

In the evaluation of spot welds, it is generally understood, for example, in the automotive industry, that an interfacial shear failure is indicative of poor weld integrity. This has generally been true for low strength steels (tensile strength equal to or less than 300 MPa [44 ksi]), in which, interfacial failure is normally associated with insufficient fusion or some sort of a weld imperfection, such as gross porosity. However, in the case of advanced high strength steels (minimum tensile strength >500 MPa [72 ksi]), interfacial fractures can occur even when there is good fusion at the weld interface. Therefore, the occurrence of interfacial fractures should not be interpreted to indicate poor weld integrity. Acceptability of weld fracture modes should be agreed upon between the fabricator and the customer.

4.9.2.3 Bend Test. This test, which was developed for aluminum and its alloys, is used for a quick check of production spot-weld soundness, particularly for freedom from cracks or microfissures. The bend test is not precise enough to calibrate equipment, evaluate machine performance, or to setup and qualify welding schedules. It is intended as a supplement to the metallographic, shear, or peel tests. It can be performed with equipment which is readily available in most shops and requires only visual examination of the specimen.

[1] For suitable etching solutions, see ASTM E340 and E407, *Annual Book of ASTM Standards*, Vol. 3.01, American Society for Testing and Materials, Philadelphia, PA, 1990 or ASM Handbook Volume 8: Mechanical Testing, American Society for Metals, Metals Park, OH, 1985. These etching solutions can contain acids and alcohols which are hazardous and can produce hazardous fumes. Care shall be used (i.e., eye protection, rubber gloves, and ventilation hoods) when using these chemicals. See 10.15 to deal with hazardous materials.

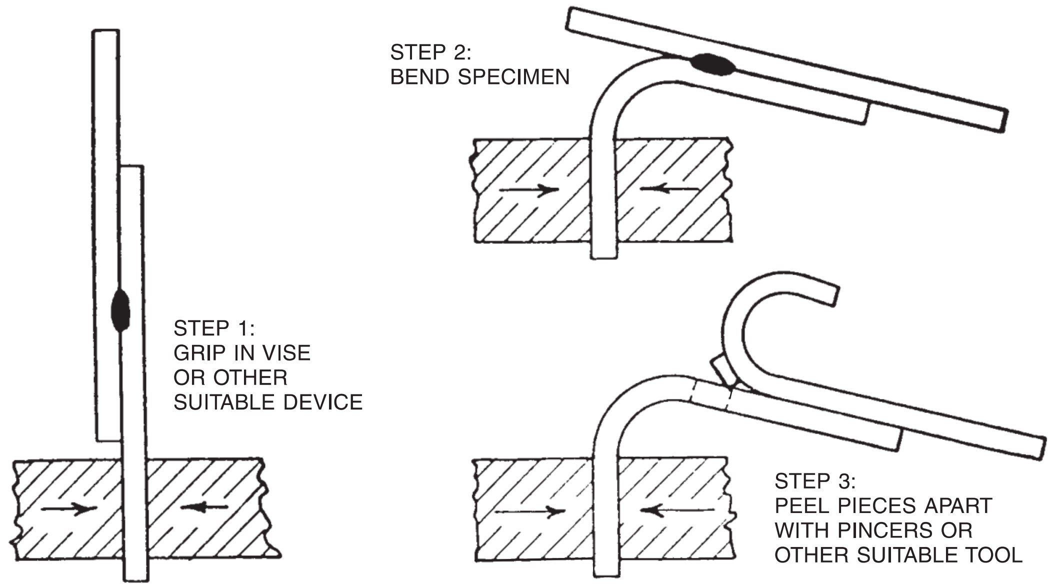


Figure 4—Peel Test

The test consists of bending a test specimen which is removed from a routine macrosection containing three welds as shown in Figure 8. The test specimen is bent along its length to the angles shown to produce a concentration of the bending stresses successively in each of the three welds. Before bending, the edges of the specimen should be rounded and smoothed to remove burrs.

After bending, the specimen is examined for the presence of cracks or any other surface defects. This test may be used for seam welds.

4.9.2.4 Chisel Test. This test consists of forcing a tool, such as illustrated in Figure 9, into the lap on each side of the weld until the lap metals separate. A weld is considered acceptable if it has an average button diameter equal to or greater than a specified value. The button size is determined in the same manner as in the peel test. This test differs from a peel test in that actual production parts, selected at random, are evaluated. When performing this test, care is to be taken so that the weld button is not damaged.

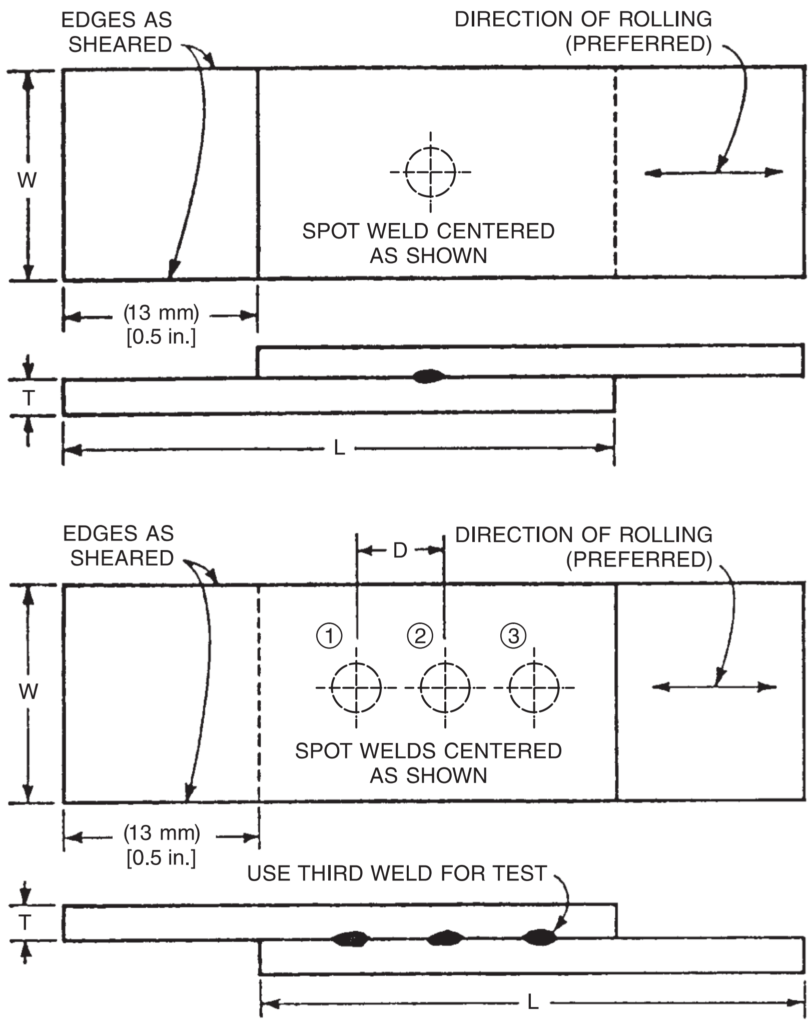
4.9.3 Nondestructive Weld-Quality Tests. These tests fall into two categories:

(1) tests for after the weld has been produced,

(2) tests for measuring the process response as the weld is being formed.

4.9.3.1 After-the-Fact Nondestructive Tests. The tests presently available cannot reliably measure weld nugget size and penetration. Nugget size determines weld strength in a given material, while penetration is associated with quality of the weld and one of the processes.

Nondestructive tests which may be used on these welded joints include: radiographic, fluorescent liquid penetrant, ultrasonic, and electrical resistance tests. A magnetic particle test may be used in place of fluorescent liquid penetrant on joints made of magnetic metals. Radiographic inspection can detect surface and subsurface defects such as cracks, porosity, nonmetallic inclusions, and metal expulsion. Fluorescent liquid penetrant inspection can detect only surface defects. Magnetic particle inspection can detect some defects near the surface in addition to surface defects. Ultrasonic and electrical resistance inspections can detect missing welds provided there is no interfacial diffusion bonding. A detailed description of these tests can be found in the latest edition of the *Nondestructive Testing Handbook* by the American Society for Nondestructive Testing.

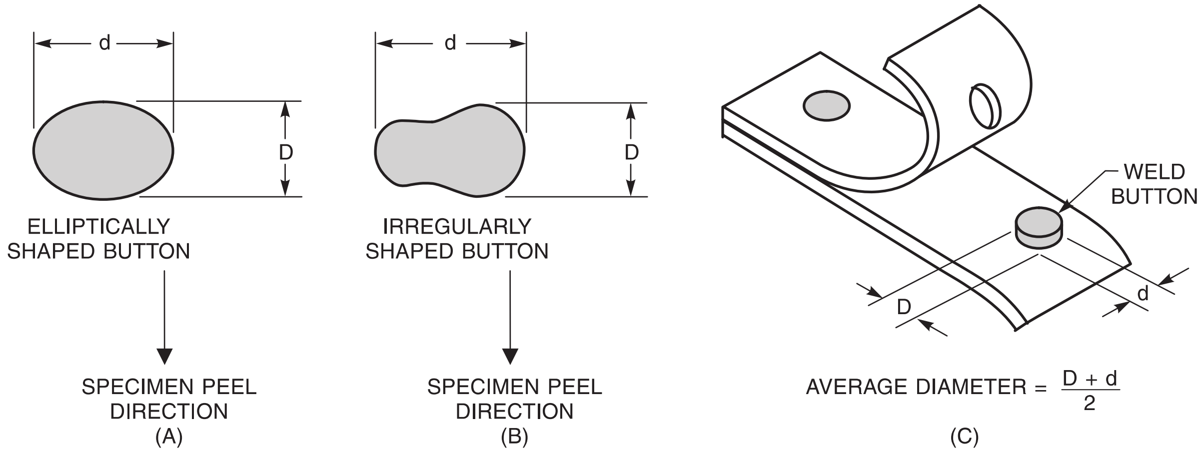


T [Thickness]		W		L		D
mm	[in]	mm	[in]	mm	[in]	
Up to 0.74	Up to [0.029]	16	[0.63]	51	[2]	See minimum weld spacing in Recommended Practice
0.76 to 1.47	[0.030 to 0.058]	25	[1.0]	76	[3]	
1.5 to 3.2	[0.059 to 0.125]	38	[1.5]	102	[4]	

Figure 5—Peel Test Specimens

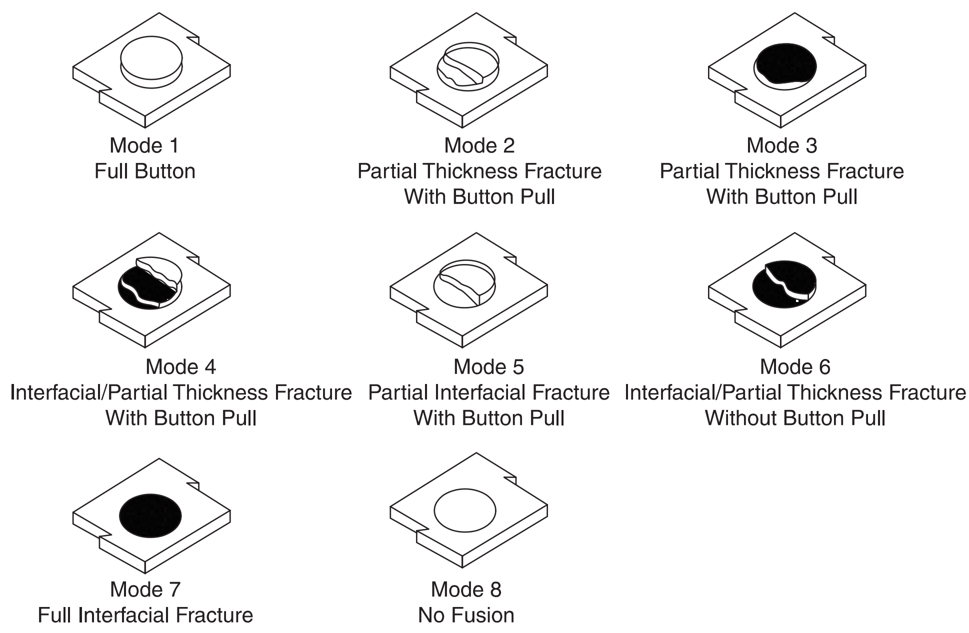
A chisel test described in 4.9.2.4 may be used as a nondestructive shop floor test, known as a pry test, to check spot-weld fusion on production parts. When the evaluation is complete, the distorted metal surface is usually hammered back to its original position. This test must not be performed on advanced high strength steels (AHSS) since the action can initiate a crevice crack at the faying surface, which can lead to failure of the weld. In this test, a tapered chisel is forced into the lap of each side of the weld being evaluated until the base metal begins to deform (acceptable) or an undersized or non-fused weld is revealed (unacceptable). This evaluation must be carefully interpreted when applied to zinc-coated steels because, in the absence of weld fusion, fused zinc may resist relatively high separation forces.

4.9.3.2 Process Response Nondestructive Tests. Presently available process monitoring systems can measure a wide range of response variables as each weld is being formed. The most common measurements are current, voltage, resistance, power, energy, electrode force, workpiece thickness, and workpiece thermal expansion. Thermal expansion



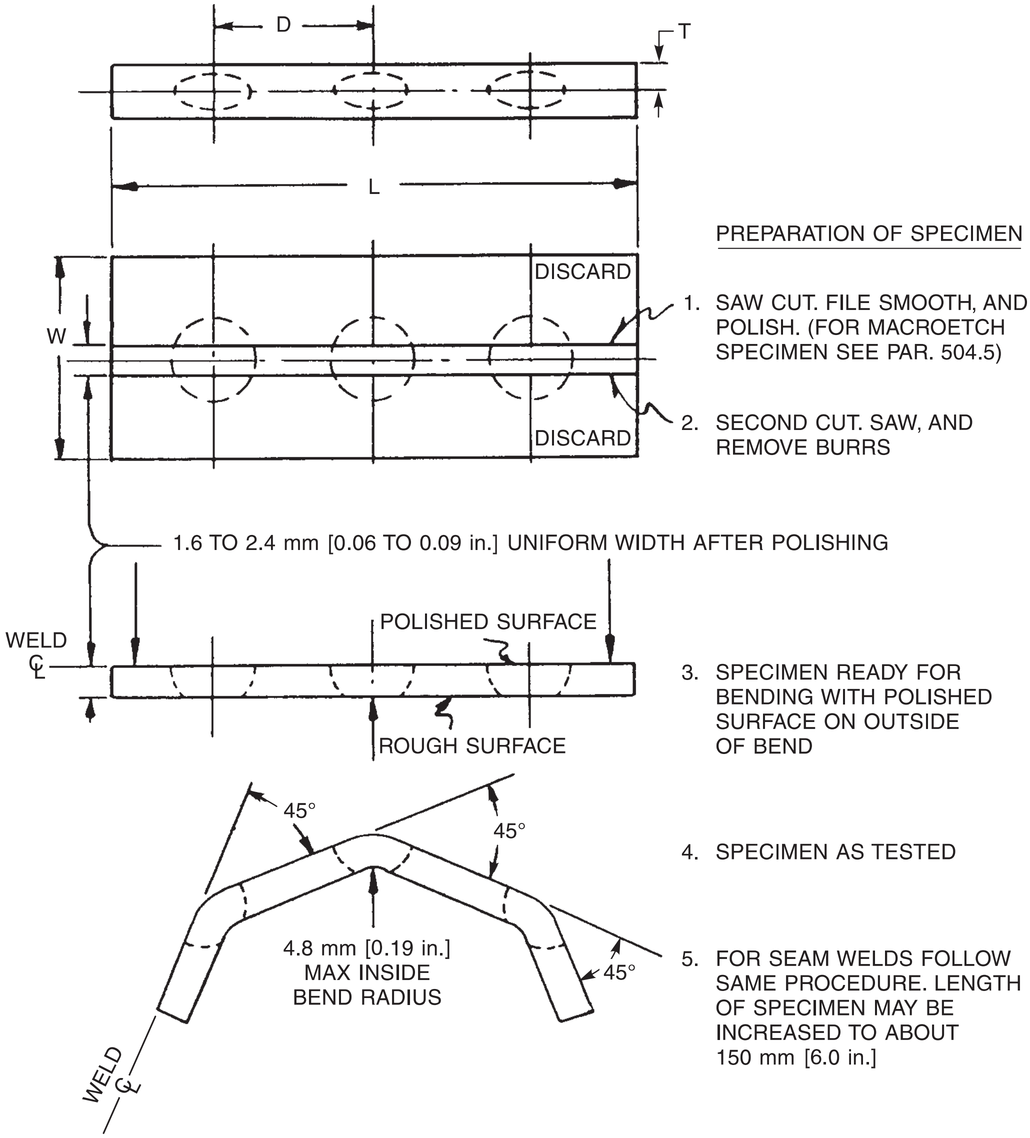
Note: Use knife edge dial caliper to measure button size.

Figure 6—Measurement of a Weld Button Resulting from the Peel Test



Source: Adapted from AWS D8.1M:2007, Figures 10–17, American Welding Society.

Figure 7—Fracture or Pullout Modes of Weld Buttons



T [Thickness]		W		L		D
mm	[in]	mm	[in]	mm	[in]	
Up to 0.74	Up to [0.029]	16	[0.63]	51	[2]	See minimum weld spacing
0.76 to 1.47	[0.030 to 0.058]	25	[1.0]	76	[3]	in Recommended Practice
1.5 to 3.2	[0.059 to 0.125]	38	[1.5]	102	[4]	

Figure 8—Bend Test Specimen

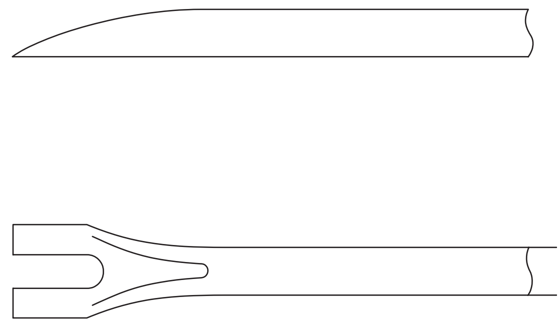


Figure 9—Chisel

exhibits good correlation with weld strength in many applications. In such applications thermal expansion provides a reliable nondestructive measurement of weld strength. By correlating the measured thermal expansion response with actual weld strength in a particular application, expansion limits can be set that correspond to established weld quality limits.

4.9.4 Statistical Weld-Quality Test. The quality of a sequence of welds can be statistically defined in terms of process capability. If the weld-quality mean and standard deviation and the specified quality tolerance limits are known, process capability can be computed as follows:

$$\text{Process Capability} = \frac{[\text{Upper Tolerance Limit} - \text{Mean}]}{3\ [\text{Standard Deviation}],}$$

$$\text{Process Capability} = \frac{[\text{Mean} - \text{Lower Tolerance Limit}]}{3\ [\text{Standard Deviation}].}$$

Choose the one which produces the lower value.

A minimum process capability specification may be established for each welding application based on the percentage of unacceptable welds that can be tolerated without taking any action to reject the welds. The following shows the percentage of welds outside of tolerance limits as a function of process capability:

Process Capability	*Percent of Welds Outside of Tolerance Limits*
0.50	13.4
0.75	2.4
1.00	0.27
1.30	0.0096
2.00	0.00000018

Operational procedures should be developed and implemented to ensure compliance with the process capability specification at all times. The mean and standard deviation of weld performance characteristics can be calculated from measurements of destructively tested components. Test coupons may be substituted in place of actual components when it can be demonstrated that measurements of test coupons correlate with measurements of actual components. Nondestructive evaluation may be substituted in place of destructive testing when the nondestructive evaluation system can reliably demonstrate that the actual process capability complies with the process capability specification.

4.9.4.1 Cause and Effect Weld-Quality Test. It should be noted statistical or periodic testing cannot prevent random discrepant welds from passing through production undetected.

Therefore, the only way to prevent unacceptable welds from passing through production undetected is to employ a monitoring system performing sufficient measurements of every weld to detect when a discrepancy occurs and notifies the operation to reject the weld or take appropriate corrective action.

4.9.5 Mechanical Property Tests

4.9.5.1 Spot-Weld Tests

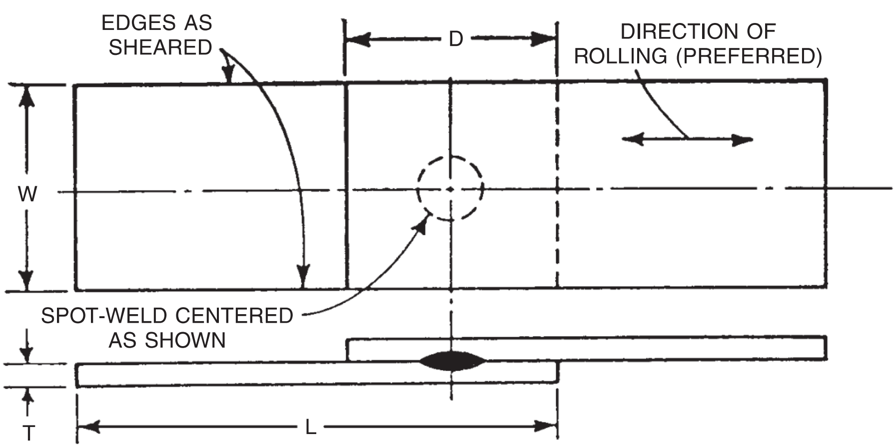
(1) Shear-Tension Test. This test consists of pulling a test specimen in tension to destruction on a standard tensile testing machine. The test specimen is prepared by joining two overlapped strips of metal with a prescribed arrangement of spot welds. The arrangements and dimensions of the test assemblies are shown in Figure 10. In a single weld test specimen, current producing the weld is equal to that provided by the machine. No shunting current is present and welds obtained may be larger than production ones. In the multiple weld test specimen, beginning from the second weld, the portion of the welding current passing through the weld may be reduced by the shunting current. This situation is more representative to production conditions. Tensile specimens are obtained by cutting the specimen. The first weld should be disregarded.

For specimens 2.6 mm [0.10 in] thick and over, it is suggested that pads be attached to specimens to avoid bending in the grips of the testing machine, as shown in Figure 11.

The ultimate strength of the specimen and the mode of failure, such as shearing of the weld metal, or tearing of the base metal, and type of fracture (ductile or brittle) are determined.

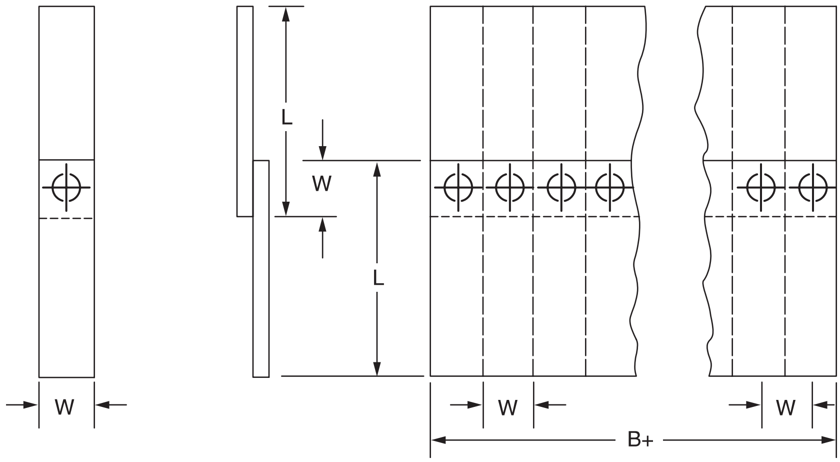
It may also be desirable to measure and report the bend angle between the weld interface and the tensile axis at fracture, as shown in Figure 12. Note that this angle may also be referred to as the angle of twist. The bend angle value is an important parameter that not only characterizes the stress conditions and the plastic deformation of the weld interface and adjacent base metal, but also can be correlated with the fracture mode of the welded joint. Normally, a small bend angle is associated with weld interface shear failure. A large bend angle is associated with the fracture of the base metal adjacent to the weld.

(2) Tension Tests. The purpose of the tension test is to provide a method to determine the spot-weld strength under tensile loading. The ultimate strength of the weld, the diameter of the weld button, and the method of fracture can also be determined. It should be noted in producing the tension test assemblies, no shunting current is present and that welds obtained may be larger than production ones.



T [Thickness of Thinner Sheet]		W [Specimen Width]		L [Recommended Length]	
mm	[in]	mm	[in]	Mm	[in]
Up to 0.76	Up to [0.030]	16	[0.63]	76	[3]
0.79 to 1.27	[0.031 to 0.050]	19	[0.75]	76	[3]
1.3 to 2.5	[0.051 to 0.100]	25	[1.0]	102	[4]
2.6 to 3.3	[0.101 to 0.130]	32	[1.25]	127	[5]
3.3 to 4.8	[0.131 to 0.190]	38	[1.5]	127	[5]
4.8 and over	[0.191] and over	51	[2.0]	152	[6]

Figure 10—Tension-Shear Test Specimen



NOTE 1.	Nominal Thickness of Thinner Sheet, in	W in, Min	Nominal Thickness of Thinner Sheet, mm	W mm, Min
	Over 0.008 to 0.030,	0.68	Over 0.20 to 0.75,	17.0
	Over 0.030 to 0.100,	1.00	Over 0.75 to 2.50,	25.0
	Over 0.100 to 0.130,	1.25	Over 0.50 to 3.20,	32.0
	Over 0.130	1.50	Over 3.20	38.0

NOTE 2. L shall be not less than 4W.
NOTE 3. Figure 1b shall be made of 5 specimens or more.

Figure 11—Spot Welds in Sheet

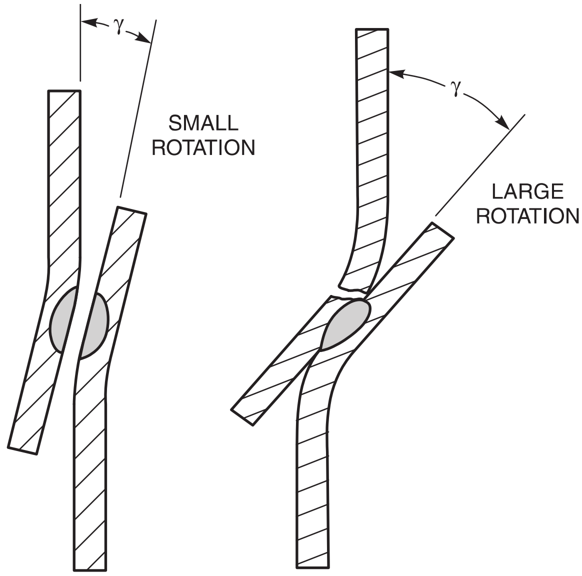


Figure 12—Twisting Angle γ at Fracture in Tension Shear Test

The ultimate tensile strength determined by this test is a better measure of sensitivity to embrittlement due to stress concentration at the spot weld than is the tensile shear strength obtained with the tensile shear test. The ratio of the tensile strength to the shear tension strength is frequently referred to as the ductility of the weld.

Two types of tension tests, the cross-tension test and the U-specimen tension test, are used as specified by the design requirements of the part being welded and the testing fixtures available.

(a) Cross-Tension Test. This test is designed to stress the weld in a direction normal to the surface of the material. Dimensions of the welded cross-tension specimens are shown in Figure 13. Special holding fixtures are constructed to apply normal tension to the specimens. It should be noted in producing the cross-tension test assemblies, no shunting current is present and welds obtained may be larger than production ones.

The fixture for holding the 50 × 150 mm [2 × 6 in] cross specimen of Figure 13 is shown in Figure 14. The fixture is intended for sheet thicknesses up to 4.8 mm [0.19 in]. Various methods of holding the fixture in the testing machine may be used, such as pin connections, wedge grips, or threaded-end testing fixtures. A self-aligning feature is desirable and precautions should be taken to prevent the specimen from slipping in the holding fixture.

The fixture for holding the 75 × 200 mm [3 × 8 in] cross-tension specimen of Figure 13 is shown in Figure 15. Figure 15a shows a specimen in the lower portion of the testing fixture.

Tension at right angles to the plane of the joint is produced by applying compression to the fixture holding the specimen. The U-shaped yokes with the hold down screws are used to partially restrain the specimen from bending by introducing semi-fixed ends to the beam represented by each separate plate. Figure 15 shows the specimen completely assembled in the fixture with the compression head of the testing machine in contact with the fixture and ready for applying load to the specimen.

(b) U-Specimen Tension Test. A tension test may also be made on U-shaped specimens as shown in Figure 16. The U-sections are welded as shown and pulled to destruction in a standard tensile testing machine. It should be noted in producing the U-specimen test assemblies, no shunting current is present and welds obtained may be larger than production ones. Supporting or spacer blocks must be provided, as shown in Figure 17, for confining the sample so that loading takes place at the weld. This test is limited to those thicknesses and metals that can readily be bent to the radius indicated. For magnesium, high-strength aluminum alloys, and other alloys that cannot tolerate the indicated radius of bend, the radius must be increased to a suitable value.

(3) Pull Test. A pull test determines the resistance of the welded joint to the opening mode of fracture. Tensile load is applied at a 90-degree angle to the joint interface as shown in Figure 18a and Figure 18b. It should be noted that this test may also be referred to as a “90-degree peel test”. It should also be noted in producing the pull test specimen, no shunting current is present with the single weld variant and welds obtained may be larger than production ones. The dual weld test provides a shunting path and may be more representative of a production condition. When preparing the test specimen the shunt weld shall be made first, followed by the test weld(s).

For this test, a conventional tensile testing machine is used to provide the tension force. The grips serve as reinforcement plates to minimize the elongation of the specimen in regions outside the weld. The distances between the sheet surfaces of the welded joint, positioned in the horizontal plane (at 90 degrees to the tension axis), and the adjacent end surfaces of the grips should be sufficiently small to minimize the elongation, but large enough so that the grip ends do not interfere with the deformation of the welded joint during the test. In preparation of a 90-degree pull arm, the weld nugget should not be disturbed. This can be achieved by clamping the nugget of the spot-weld specimen in a vise so that the edge of the vise is aligned with the “pull edge” of the nugget and bending one sheet of the specimen to 90 degrees with respect to the other sheet. The distance from the load axis of the pull arm to the nugget’s pull edge should be equal to the minimum bend radius of the metal to avoid cracking. For a given material and temper, the selected or experimentally determined minimum bend radius should be the same for a data comparison. For ductile metals, the minimum bend radius of curvature should not exceed the thickness of one of the welded sheets.

(4) Torsion-Shear Test. A torsion-shear test for evaluating spot welds may be used where a measure of strength and ductility is required. A typical setup for this test is shown in Figure 19. Note, no shunting current is present and welds obtained may be larger than production ones. Torsional shear is applied on the weld of a square test specimen by placing the specimen between two recessed plates. The upper plate is held rigid by a hinge, while the lower is fastened to a rotating disk. After the specimen is placed in the square recess of the lower plate, the upper plate is closed over it and locked in position. Torque is applied by means of a rack and pinion attached to the disk. It is important that the upper and lower sheets of the specimen be engaged separately by the two plates and the weld be centrally located with respect to the axis of rotation.

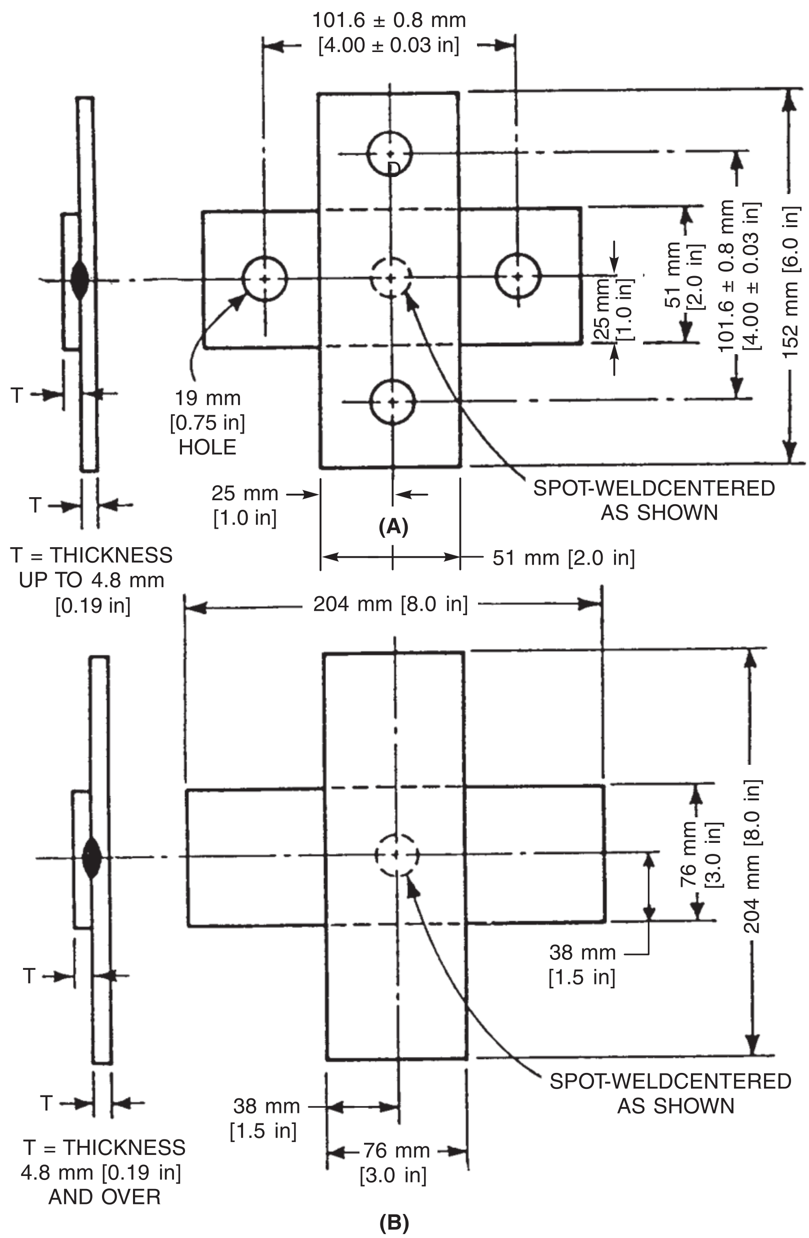


Figure 13—Cross-Tension Test Specimen

Three values are determined for the weld area:

(1) Ultimate torque required to twist the weld to destruction (computed by multiplying the maximum load in newtons [pounds-force]) by the moment arm in m [in].

(2) Angle of twist at ultimate torque (measured by the angle of rotation at maximum load).

(3) Weld diameter (measured after the test specimen is broken).

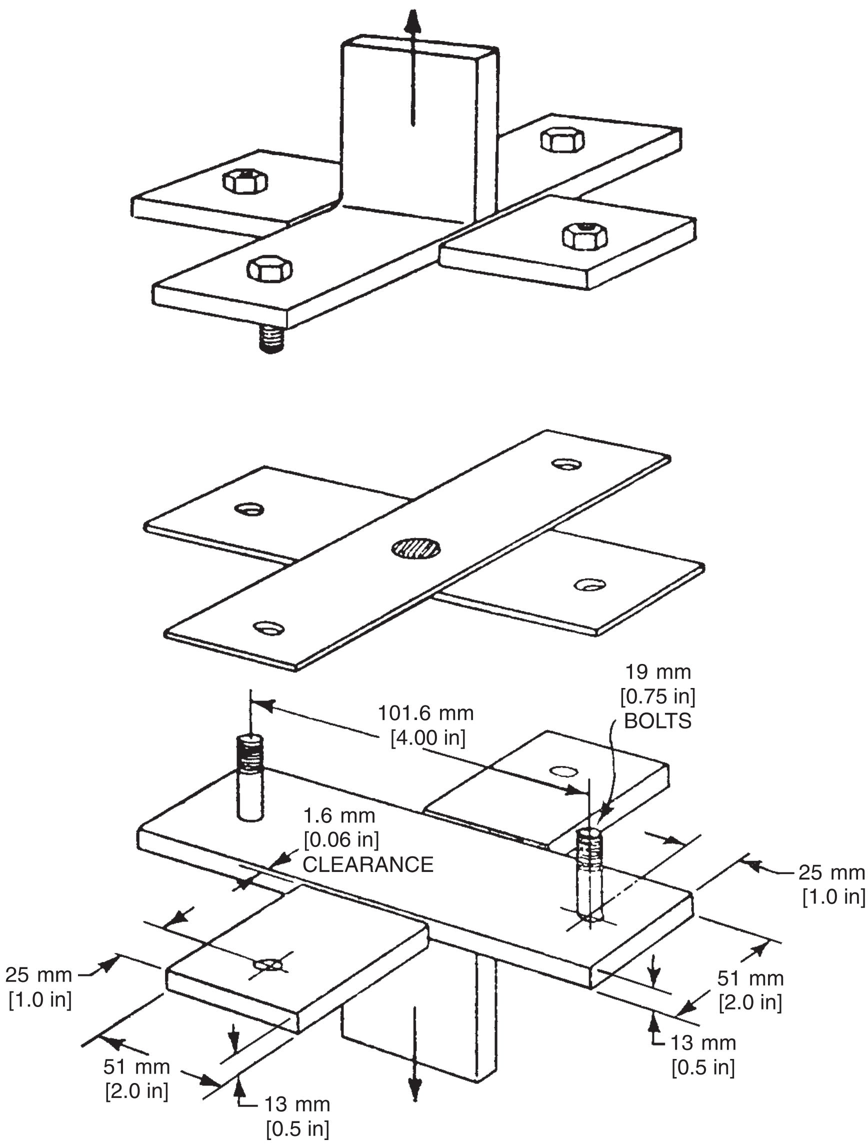


Figure 14—Fixture for Cross-Tension Test (for Thicknesses up to 4.8 mm [0.19 in])

The weld strength can be determined using the ultimate torque and weld diameter, and the ductility by the angle of twist.

It is possible to use the test values obtained (ultimate torque, angle of twist, and weld diameter) to indicate quality. This may be done by using the standard torsional formula:

$$S_t = \frac{Mc}{I}$$

where

I = moment of inertia (m^4 [in^4]);

S_t = torsional shear stress (Pa [psi]);

M = torque (N-m [inch pound-force]); and

c = distance from external fiber to central axis (m [in]).

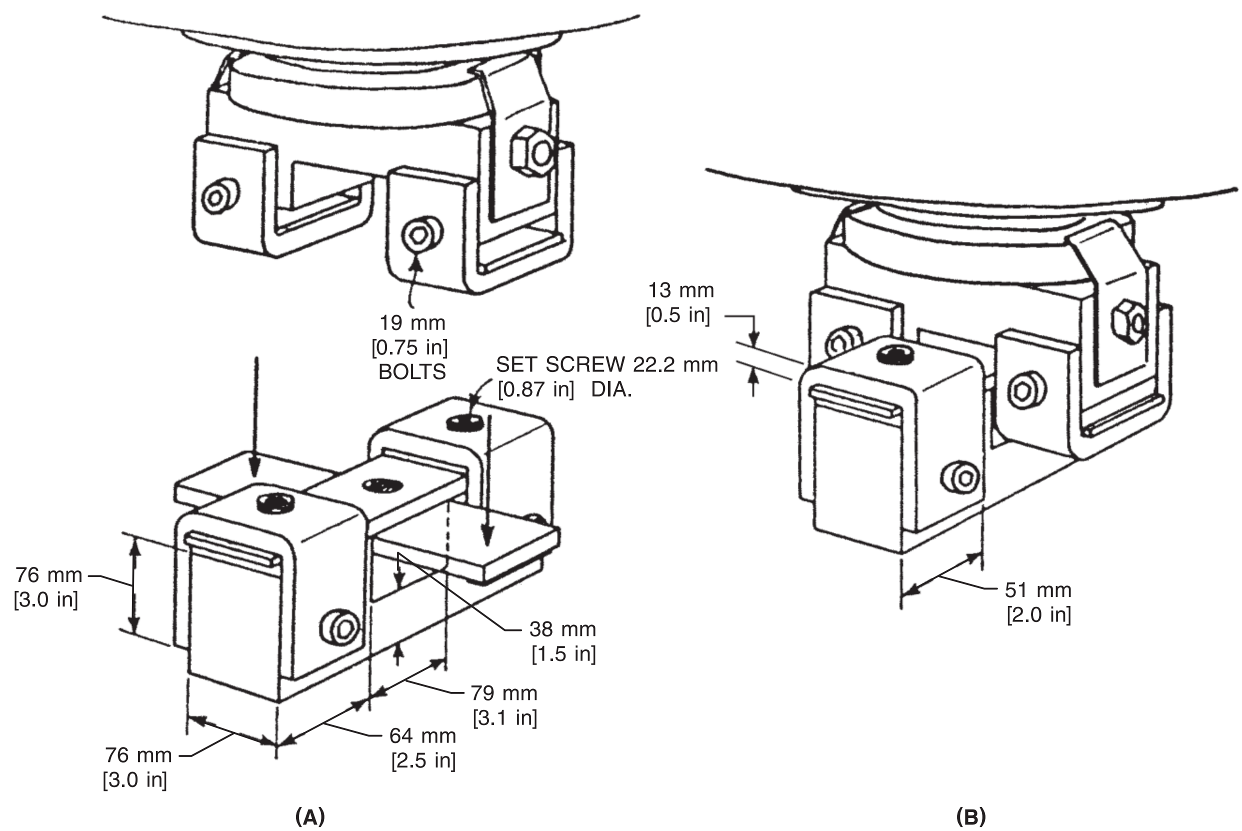


Figure 15—Fixture for Cross-Tension Test (for Thicknesses 4.8 mm [0.19 in] and Over)

The torsional shear stress values obtained for the external fibers, termed the modulus of rupture, are directly proportional to the shear tension stress. The modulus of rupture, as determined by actual tests on low-carbon steels, was found to be approximately twice the shear tension stress.

An additional benefit of torsional testing is that it also allows the determination of shear tension strength by using the following equations:

$$S_t = 2S_L \tag{1}$$

where

S_L = tension shear stress

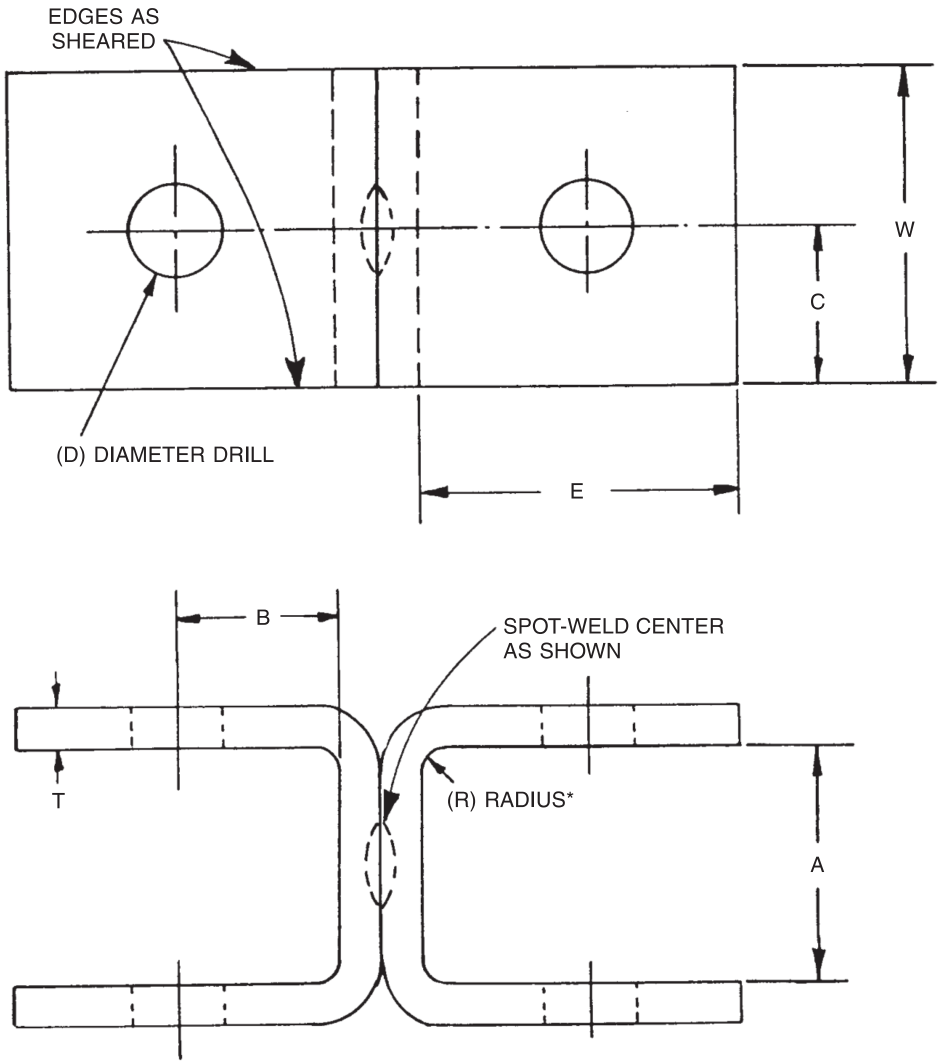
$$\frac{Mc}{I} = \frac{2L}{A}, \tag{2}$$

where

L = straight shear load and
A = cross-sectional area.

Substituting ultimate torque (T) for torque M, and L for straight shear load,

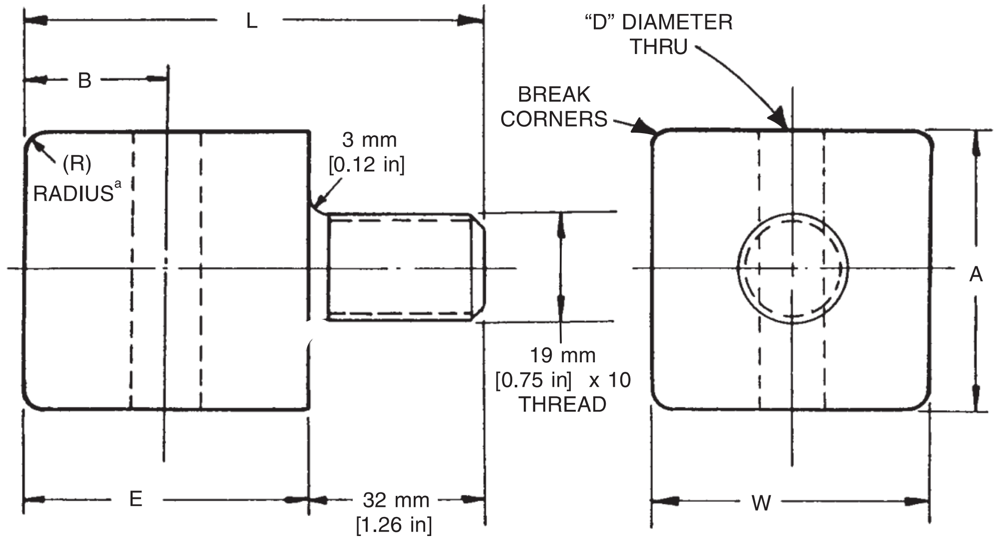
$$\frac{\frac{TD}{2}}{\frac{\pi D^4}{32}} = \frac{2L}{\frac{\pi D^2}{4}}$$



T [Thickness]		W		A		B		D		E		R[a]	
mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in
Up to 2.54	Up to [0.100]	25	[1]	25	[1]	13	[0.5]	8.3	[0.33]	25	[1]	4.0	[0.16]
2.56 and over	[0.101] and over	51	[2]	51	[2]	25	[1]	14.3	[0.56]	51	[2]	6.4	[0.25]

[a] For magnesium, high-strength aluminum alloys and other alloys that cannot tolerate these radii, the radius must be increased to a suitable value within the limits of the capability of the particular material. It is desirable to form these specimens without the necessity of heating as this will modify the results.

Figure 16—U-Test Specimen



T [Thickness]		W		A		B		D		E		R[a]		L	
mm	[in]	mm	[in]	mm	[in]	mm	[in]	mm	[in]	mm	[in]	mm	[in]	mm	[in]
Up to 2.54	Up to [0.100]	25	[1]	25	[1]	13	[0.5]	8.7	[0.34]	25	[1]	4.0	[0.16]	57	[2.25]
2.56 and over	[0.101 and over]	51	[2]	51	[2]	25	[1]	14.3	[0.56]	51	[2]	6.4	[0.25]	82	[3.25]

[a] For magnesium, high-strength aluminum alloys and other alloys that cannot tolerate these radii, the radius must be increased to a suitable value within the limits of the capability of the particular material. It is desirable to form these specimens without the necessity of heating as this will modify the results.

Figure 17—U-Tension Test Jig

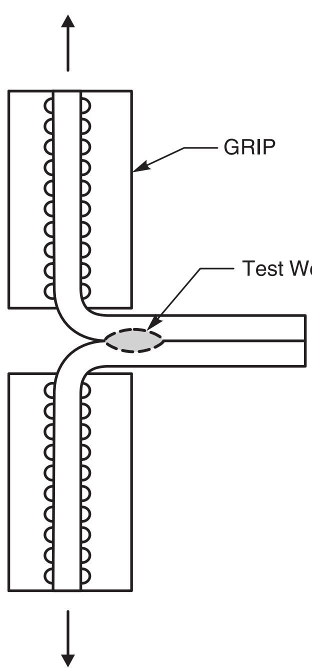
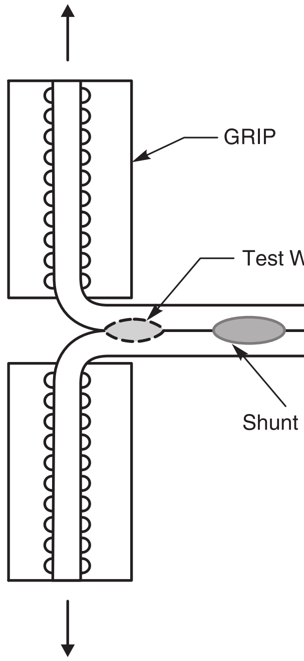


Figure 18a—Pull Test (90-Degree Peel Test)—Single Weld



T [Thickness of Thinner Sheet][a]		W [Specimen Width][b]		L [Recommended Length][c]	
mm	[in]	mm	[in]	mm	[in]
Up to 0.76	Up to [0.030]	16	[0.63]	102	[4]
0.79 to 1.27	[0.031 to 0.050]	19	[0.75]	102	[4]
1.3 to 2.5	[0.051 to 0.100]	25	[1.0]	127	[5]
2.6 to 3.3	[0.101 to 0.130]	32	[1.25]	152	[6]
3.3 to 4.8	[0.131 to 0.190]	38	[1.5]	152	[6]
4.8 and over	[0.191] and over	51	[2.0]	178	[7]

[a] Bend radius based on material property limitations. Bend located at center of recommended length.
[b] Recommended minimum grip length is 40 mm [1.6 in] for thickness of <1.3 mm [0.051 in] and 60 mm [2.4 in] for thickness of ≥1.3 mm [0.051 in].
[c] Recommended spot spacing is based on production requirements and may drive the need for a longer test coupon.

Figure 18b—Pull Test (90-Degree Peel Test)—Dual Weld

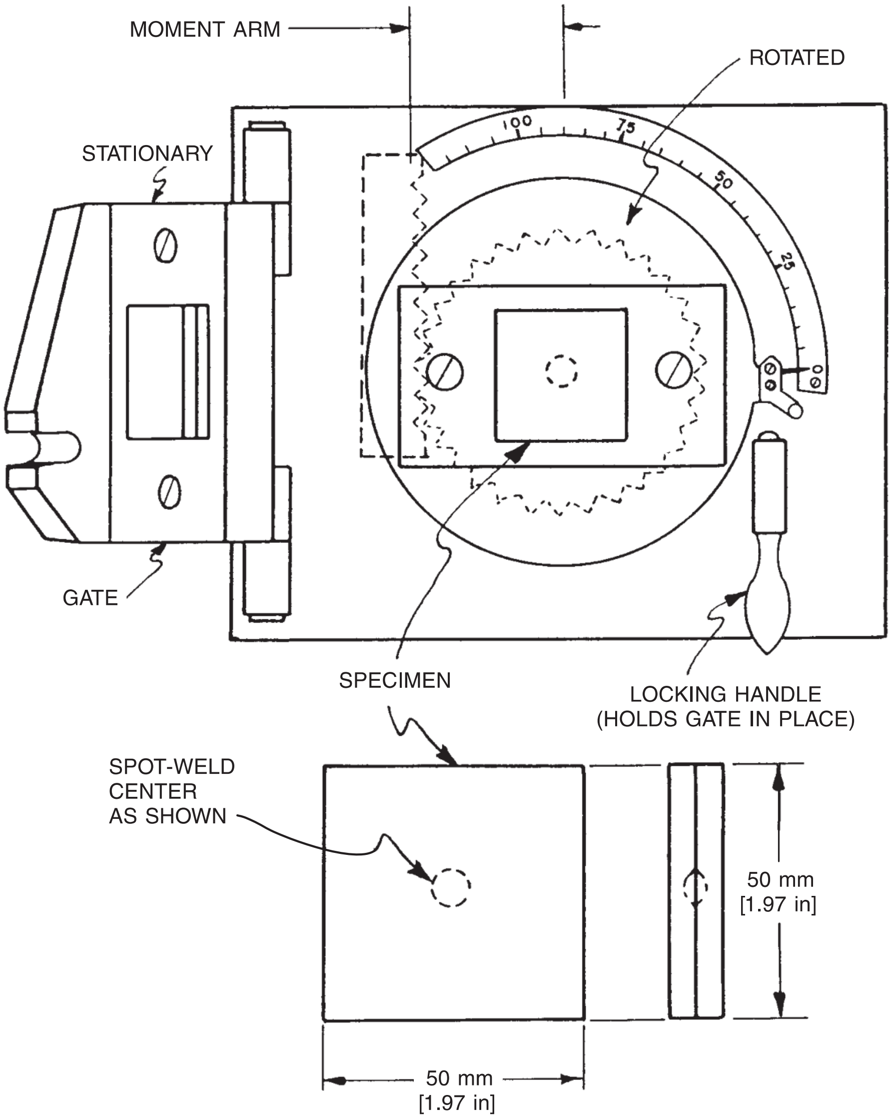


Figure 19—Test Specimen and Typical Equipment for Torsion-Shear Test

$$\frac{16T}{\pi D^3} = \frac{8L}{\pi D^2}$$

$$L = \underline{2T}, \text{ or, } D$$

$$\text{shear load (N [pound-force])} = \frac{2 \text{ [ultimate torque (N-m [inch pound-force])}}{\text{weld diameter (m [in])}} \quad (3)$$

The above formula gives the approximate relation between shear strength and torque required to shear the weld, thereby permitting evaluation of the shear strength by torsional testing, or by calculating the ultimate torque from the shear load.

When tested and computed as indicated above, the strength values for single spot welds may be determined.

(5) Impact Test. The impact test differentiates between degrees of weld resistance to fracture under impact load. Six types of impact tests are described here. Note, for all single weld impact test assemblies, no shunting current is present and welds obtained may be larger than production ones.

(a) Shear-Impact Test (limited to thicknesses up to 3.2 mm [0.12 in]). A satisfactory shear-impact test for spot welds may be obtained by using the 50 × 150 mm [2 × 6 in] shear tension specimen (see Figure 12), and a modified 50 to 100 N [11 to 22 pound-force] pendulum-type impact testing machine. To satisfactorily test welds in sheets up to and including 3.2 mm [0.12 in] thickness, it is necessary to have pendulum bobs of different weights.

In this type of test, the specimen is held by serrated wedge grips in the special pendulum bob and cross-head attachments. When the machine is operated, both the cross-head and bob, which are connected by the welded specimen, fall until the cross-head is caught by adjustable anvils at the bottom of the pendulum swing. The pendulum bob is free to continue its swing, and will do so, provided sufficient energy is available to fracture the specimen. The residual swing of the pendulum indicates the impact load, in joule (newton-meters) [foot-pounds-force], to break the weld. Care should be taken to properly tighten the wedge grips so that no errors are introduced by slippage of the specimen during the test. If grip slip- page is a serious problem, pin connections may be used to supplement the grips. The striking surface of the cross-head and the impact-receiving surface of the anvil should be perpendicular to the longitudinal axis of the specimen to preclude errors caused by twist load. Tests may be made at various velocities which should be not less than 3 m/s [10 ft/s] or more than 6 m/s [20 ft/s]. Velocity should always be stated as a maximum tangential velocity of the cross-head striking surface. The impact value should be taken as the energy absorbed in breaking the weld, and is equal to the difference between the energy in the entire striking unit, which may, for example, consist of pendulum, pendulum bob, specimen and cross-head, at the instant of impact with the anvil and the energy remaining after breaking the weld. For maximum energy, the kinetic energy imparted to the tooling should be taken into account. Similar to the requirements for shear-tension test, it is desirable to determine and report the bending angle at fracture as measured after the test.

When making shear-impact tests, some of the energy is absorbed in plastic deformation of the sheets. In order to control the extent of this deformation, the distance between grips should be not less than 125 mm [4.9 in].

Since large changes in spot-weld impact strength occur with relatively small changes in sheet thickness and weld size, the coverage obtained by any one pendulum bob assembly is limited.

(b) Cross-Tension Drop-Impact Test. Since the range of the ordinary pendulum-type impact testing machine will not permit shear-impact tests to be made on spot-welded sheets of thicknesses greater than 3.2 mm [0.12 in], a different procedure must be used to apply impact loads to welds in the heavier gage metals. The most critical direction in which an impact load may be applied to spot welds in heavy plate is in a direction normal to the plate surfaces. This may be accomplished using a test specimen similar to that used for the cross-tension test with added reinforcement as shown in Figure 20.

The principal components of a drop weight impact machine are a vertically guided, free-falling weight, a rigidly supported anvil, and a pair of calibrated springs placed below the specimen or other type of force transducer arrangement to measure the remaining energy of the weight after the weld fractures (see Figure 21). The lower portion of the weight is designed as a fork to assure that the impact of the weight will be applied equally to both sides of the lower plate of the specimen. The width of the opening between the two prongs of the fork of the weight is made 79 mm [3.12 in], 3 mm [0.12 in] greater than the specimen plate width of 76 mm [3.0 in] to permit the small clearance between the inside surfaces of the fork and the clamped upper plate.

When calibrated springs are used to measure the remaining energy after the test, the maximum deflection of the springs may be indicated by an aluminum push rod moving between a pair of bronze friction plates. The amount of friction may be controlled by means of spring-loaded machine screws. An arm on the aluminum push rod provides a convenient place for an indicator dial gauge to be used to measure the maximum deflection of the springs (see Figure 21). A calibration curve for residual energy may be obtained by dropping the weight from various heights corresponding to various potential energies of the moving system.

The results obtained with the cross-tension drop-impact test are subject to two types of error. Both of these are concerned with the behavior of thinner plates and the softer types of steel. One source of error is the inability to restrain the lower plate against bending. In this case, if the lower plate is thin and soft, too much bending will be produced, and either the specimen will not break or a large portion of the impact energy will be absorbed in bending of the plate. Although the ability of a weld to force the plate to bend may be a good indication of weld quality, the resultant impact energy absorbed by bending will not be a good measure of the weld strength. On the other hand, severe plastic deformation of the plate material in the vicinity of the weld is a much better indicator of weld quality. Therefore, plate bending at some distance from the weld should be avoided. The second source of error in impact testing is bending of the upper plate and slippage of the specimen in the clamps. Both of these cause absorption of additional energy, and a true measure of weld toughness is not obtained.

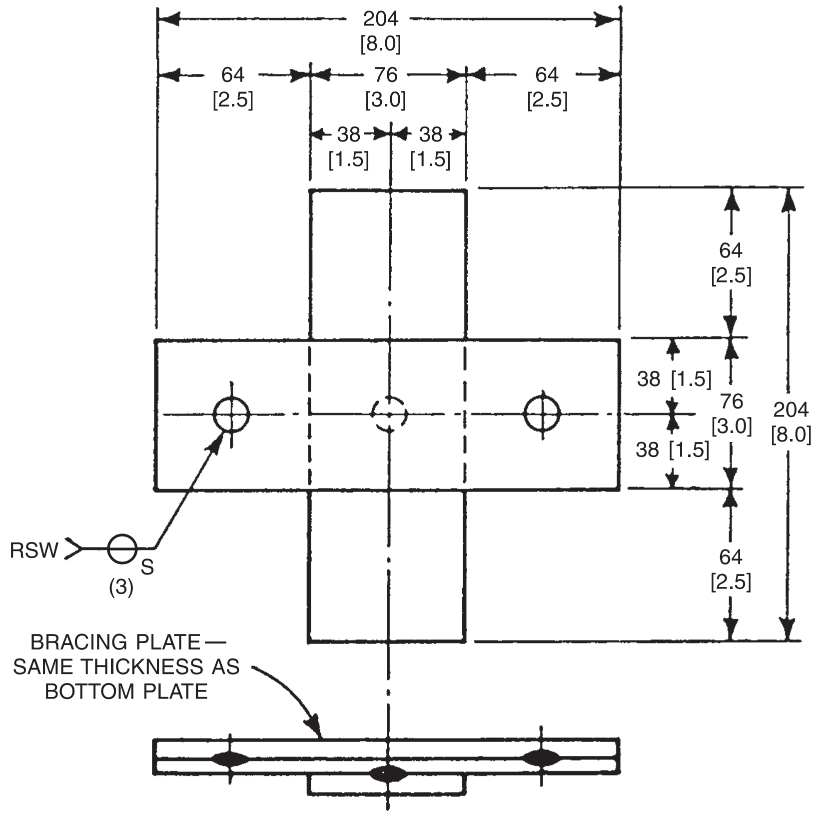


Figure 20—Drop-Impact Test Specimen

In order to avoid the possibilities for the errors mentioned above, two methods may be used to minimize bending and grip slippage in the upper plate. One is to provide serrated jaws for clamping to prevent slippage. The other is to place another plate directly over the upper plate and to attach these plates at their ends by additional spot welds, as illustrated in Figure 20. In this case, the extra plate is in compression during the test, preventing excessive plate bending due to grip slippage. In the testing of a thin plate welded to a thicker one, the heavier plate is arranged to be struck by the falling weight. The precautions as mentioned above should be used with the upper plate to ensure a satisfactory impact test. If both plates are thin and soft, it may be necessary to reinforce the lower plate in a manner similar to that used to stiffen the upper plate.

(c) U-Specimen Shear-Impact Test. This test utilizes the specimen made by joining two U-shaped sections back to back by a single spot weld as shown in Figure 16. The specimen is dynamically loaded in a pendulum-type impact testing machine with at least a 1 000 N (225 pounds-force) capacity. The test fixture is so designed that the force applied in fracturing the specimen is essentially in shear as shown in Figure 22. The operation of this test is similar to that described for the shear-tension test. The energy (N [pounds-force]) consumed in fracturing the specimen and the mode of failure is recorded.

(d) U-Specimen Tension-Impact Loading Test. This test also utilizes the U-shaped test specimen shown in Figure 16. In this case, the test fixture is so designed that the forces applied in fracturing the specimen are in tension as shown in Figure 23. In all other respects, this test is the same as the U-specimen shear-impact test.

(e) Instrumented Impact Test. The instrumented impact test electronically records the load versus time and the impact energy versus time traces to follow the dynamic fracture process of the specimen. The instrument consists of:

- load transducer placed on the pendulum bob to sense the specimen loading,
- electronic signal conditioning circuit, and
- graphic recording equipment for plotting the transducer output versus time.

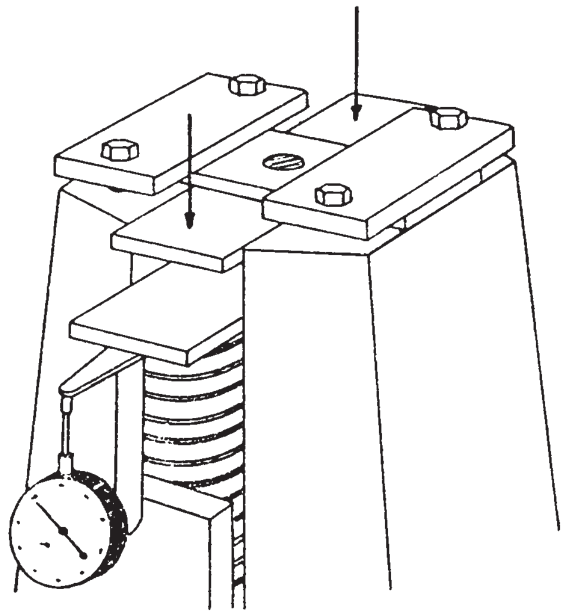


Figure 21—Drop-Impact Test Machine

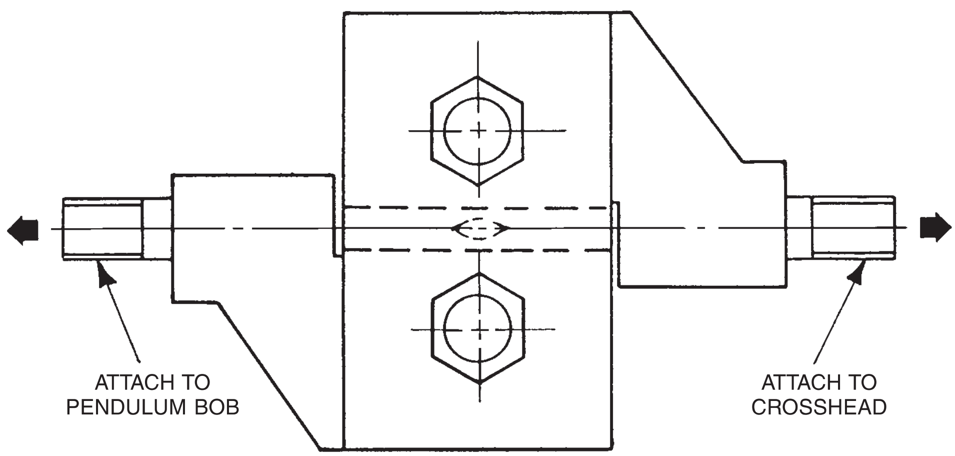


Figure 22—Test Fixture for Shear-Impact Loading Test

For certain alloys and specimen configurations, load signal oscillation may occur and become excessive. The accuracy of load values is assured if sufficient damping is achieved. For an accurate determination of the peak load, it should be required that the time to the peak load is at least three times the period of the oscillation.

(6) Fatigue Test. The fatigue test is performed using the shear test specimen (see Figure 8). The specimen is mounted in the fatigue tester using utmost care to align the weld with the force center. Fatigue tests of spot and projection welds are often conducted with a ratio of minimum stress to maximum stress of 0.1. Maximum tensile load should never occur at less than 25 percent of the machine's operating range. There are different types of fatigue testing machines, such as

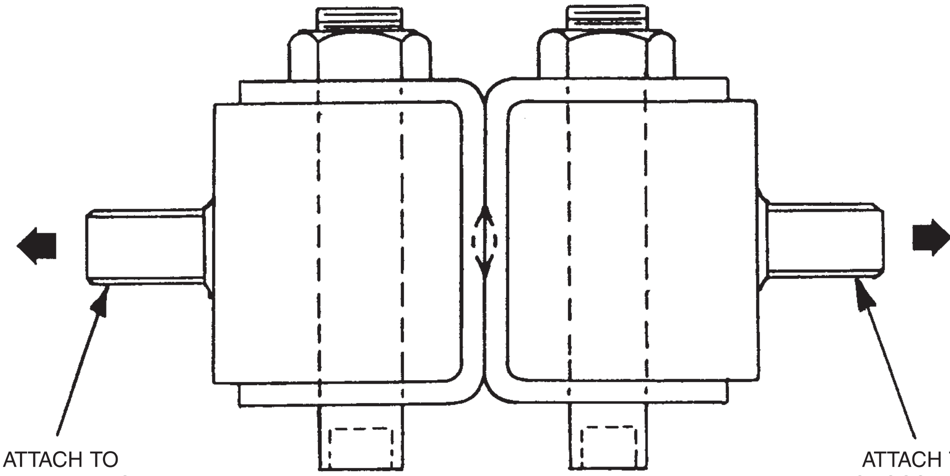


Figure 23—Test Fixture for Tension-Impact Loading Test

the (1) mechanical (eccentric crank, power screws, rotating masses) type, (2) hydraulic or electrohydraulic type, and (3) electromechanical or magnetically driven type. A typical fatigue test set-up is shown in Figure 24.

The selected fatigue testing machine should permit cycling between the intended stress or strain limits. For constant amplitude low-cycle (less than 10^5 cycles) fatigue, the machine control stability should be such that the respective stress or strain limit is repeatable from cycle to cycle to within 0.5 percent of the average control limit and repeatable over the test duration to within 2 percent of the average control limit. Either strain rate or frequency of cycling should be constant for the duration of each test. Although constant strain rate testing is often preferred, and is experimentally more tractable than constant frequency testing, the latter may be of greater practical significance to the fatigue analysis of resistance welds for certain applications. In high-cycle fatigue tests, the test loads should be monitored continuously in the early stage of the test and periodically maintained.

The machine should have minimal backlash in the loading train. The varying stress, as determined by a suitable dynamic verification, should be maintained at all times to within 2 percent of the machine operating range. Below a certain frequency (e.g., 170 Hz depending on the metal), the fatigue effects due to frequency are negligible. Above this frequency, the effect of frequency on the fatigue strength may be significant and should be reported particularly if the materials are strain rate sensitive. As in the shear-tension test, the rotation (twisting) angle (Figure 12) of the weld interface should be recorded (e.g., by photographs) to characterize the stress conditions and plastic deformation, and to correlate it with the fracture mode of the welded joint and adjacent base metal.

To evaluate the fatigue performance of the welded joint, the following information should be reported:

(1) Total number of cycles to failure (N_f), which should be accompanied by the following information:

(a) The failure definition used in the determination of N_f (e.g., crack size or complete separation, etc.).

(b) Location of crack initiation.

(c) Frequency of cycling and shape of load time curve.

(d) Mode of control (e.g., load, stress, continuous strain control, strain limit control, etc.)

(e) Axial stress ratio R, where:

$$R = \frac{\textit{Minimum axial stress}}{\textit{Maximum axial stress}}$$

For zero minimum axial stress, $R = 0$.

(2) Rotation angle immediately before or at failure.

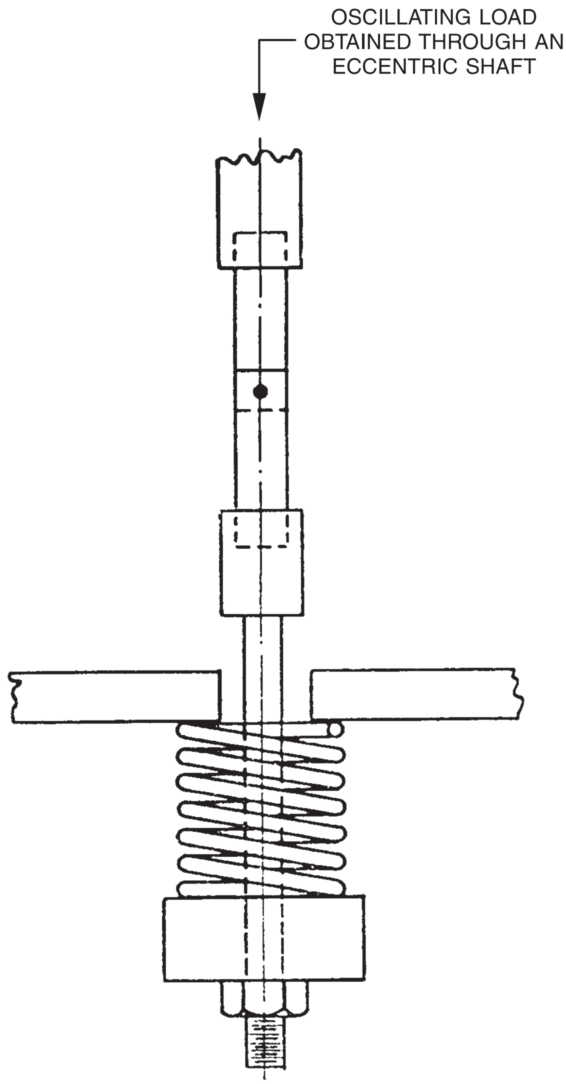


Figure 24—Fatigue Testing Machine

4.9.5.2 Seam-Weld Tests

(1) Shear-Tension Test. To determine the shear strength of a seam weld, the shear-tension test specimen (see Figure 10) previously described should contain a seam weld, in place of the spot weld, perpendicular to the axis of the tensile load.

(2) Pillow Test or Pressure Test. Seam welding is an extension of spot welding where the spots provide a continuous weld. This type of weld is usually employed where leak-tightness is required. A test simulating the service conditions of the welded joint furnishes the best measure of the weld quality.

For this purpose, two flat plates of the same thickness, as used in production, are prepared and seam welded around the outside edge, sealing the space between the plates. A pipe connection is then welded to a hole drilled in the top plate as shown in Figure 25. After the assembly is attached to a hydraulic system, pressure is applied.

The pillow can be so distorted as to cause excessive loading in some spots with little loading in other spots. Consequently, it may be necessary to restrict deformation of the pillow by inserting a plate above and below it while testing, particularly in soft or thin material.

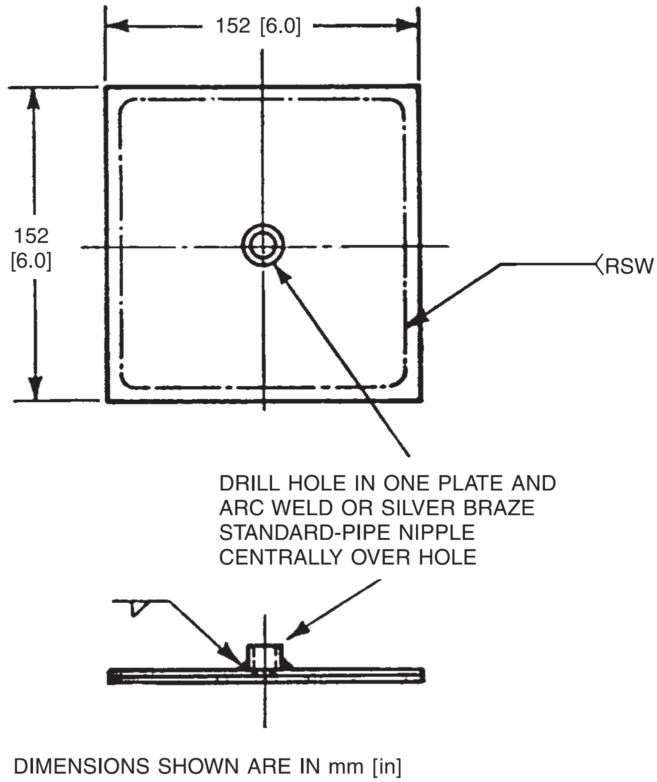


Figure 25—Pillow Test for Seam Welds

The measure of a good weld is no leakage at a prescribed pressure or when failure occurs in the base metal. The pillow specimens can be tested under cyclic pressures to determine the fatigue strength of the welded joint.

5. Projection Welding

5.1 Introduction. Projection welding is a resistance welding process producing a weld by the heat obtained from the resistance to the flow of the welding current. The resulting welds are localized at predetermined point by projections, embossments, or intersections. The point of contact is with a local geometric extension (projection) of one (or both) of the parts. These projections are used to concentrate heat generation at the point of contact. Projection welding can typically be done using lower currents, lower forces, and shorter welding times than a similar spot-welding application.

Projection welding applications are generally classified as either embossed or solid projection welding. These are shown in Figures 26 and 27.

Embossed projection welding is generally a sheet-to-sheet joining process in which a projection is stamped or pressed into one or more of the sheets to be joined. During welding, heating is initially concentrated at the contact point and in the walls of the projection. Early in the process, the projection almost completely collapses back into the original sheet. Weld development proceeds in a manner similar to spot welding, whereby a fused weld nugget is formed at the point of current concentration. Completed embossed projection welds are often indistinguishable from conventional resistance spot welds.

In solid projection welding, the projection may be machined or formed on one of the two components being joined. During resistance heating, the contact point and the projection itself experience a significant increase in temperature. The projection then collapses by both penetrating the opposing material and by upsetting (or extruding to the periphery). This weld typically resembles a solid-state diffusion weld, with a minimal fused zone, rather than a spot weld.

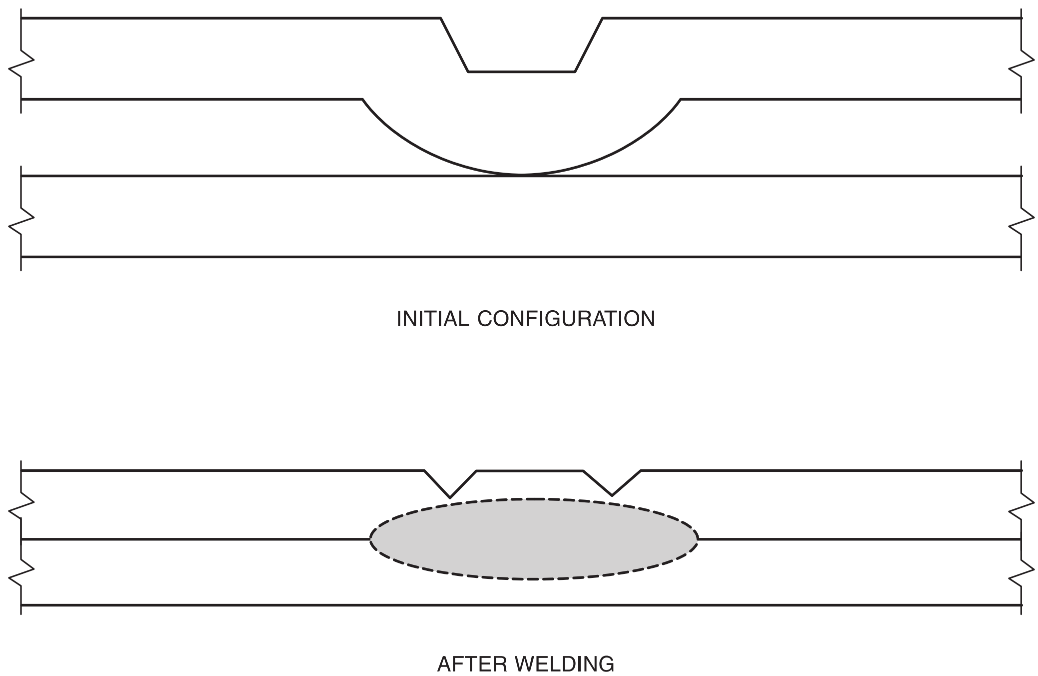


Figure 26—Typical Stack-up Configuration for Embossed Projection Welding of Sheet

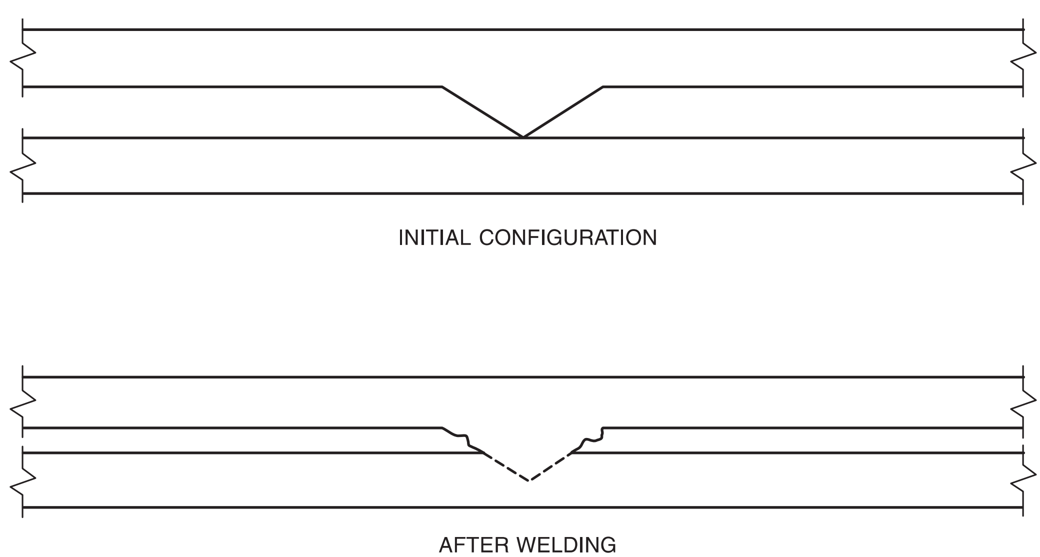


Figure 27—Typical Configuration for Solid Projection Welding

Since the projections typically collapse during the projection welding process, the strength of the material being welded, particularly at high temperatures, affects the projection weldability. Materials that maintain their strengths up to relatively high temperatures permit substantial heating to occur before the projection collapses. Premature collapse of the projection results in a reduction in current density which reduces the concentrated heat generation from resistance heating. This prevents the projection contact area temperature from increasing high enough to promote satisfactory welding. Bulk resistivity, to a lesser degree, also plays a role in projection welding. Increased bulk resistivity has the effect of reducing the effectiveness of the projection as a current concentrator. With increasing bulk resistivity, there is a tendency for delocalized heating and general, rather than local, collapse of the projection. As a result, high resistivity materials are more difficult to projection weld.

Materials that are ideal for projection welding include mild steels and low-alloy, nickel-based materials. These materials have adequate strength at high temperatures, proper resistivity, and readily dissociatable surface oxides to promote welding. Stainless steels and higher alloy content nickel-based materials are more difficult to weld because of their high temperature strength and adherent surface oxides. Copper and copper alloys can also be projection welded. Projection welding is preferred over spot welding because of the difficulties these highly conductive materials cause in spot welding. Aluminum and aluminum-based alloys are quite difficult to projection weld because of the tenacious aluminum oxide coating associated with aluminum and the low strength of most aluminum alloys at high temperatures (resulting in premature projection collapse). Titanium alloys are also difficult to weld using projections because of their high resistivity and low strength at elevated temperatures, which promotes premature projection collapse.

5.2 Embossed Projection Welding

5.2.1 Projection Design and Welding Parameters

5.2.1.1 Heavy-Gauge Sheet. Projection welding heavy-gauge steels is nominally an embossed projection welding process. However, the process has many of the characteristics of solid projection welding because of the higher apparent material strengths associated with the larger masses. Projection designs, in addition to defining the geometry of the projection, normally provide an annular relief for the projection material which is forged or extruded to the side during welding similar to that of solid projection designs. Projection geometries for steels ranging from 3.2–6.35 mm [0.125–0.250 in] are presented in Table 37. Process requirements for forming these welds are presented in Table 38. To prevent preflashing of the projection on initiation of the welding current, upslopes are recommended. In addition, since weld porosity is often a concern, forge forces are also recommended. All welding schedules shown are single-pulse welding schedules. As with spot-welding heavy section steels, however, excessive electrode wear may be a concern. In such applications, pulsation welding schedules might be recommended to alleviate tooling wear.

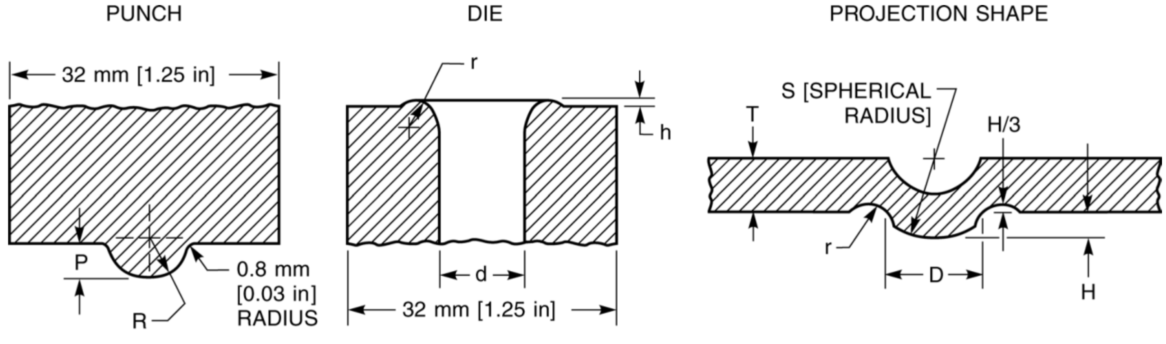
5.2.1.2 Intermediate-Gauge Sheet. Projection welding intermediate gauges of steel, 0.5–3.2 mm [0.020–0.125 in] is well established using single-point projections with single-impulse welding schedules. Projection stamping die designs are given in Tables 37 and 39 through 41. Process requirements are given in Tables 42 through 44. These gauges typically require lower forces and shorter welding times for projection welding compared to spot welding.

5.2.1.3 Thin-Gauge Sheet. Projection welding thin-gauge steel sheet, less than 0.5 mm [0.020 in], differs significantly from projection welding intermediate sheet because of the mechanical instability of the single point projections. Annular projections are typically recommended for these gauges to provide added projection strength to avoid premature projection collapse. Annular projection geometry and recommended welding process parameters are presented in Table 45.

5.2.1.4 Dissimilar Metal Thicknesses. Projection welding is ideally suited for joining materials of dissimilar thicknesses. The projection is placed on the thicker sheet (for heat balance), using the recommended projection design for that sheet (see Table 46). The projection has the effect of concentrating the heat at the contact surface.

5.2.2 Embossed Projection Dimensions. Table 47 provides the projection dimensions based on the applicable metal thickness combinations.

Table 37
Projection and Die Geometries for Welding a Range of Heavy-Gauge Steels



TOOL STEEL HARDENED TO 50-52 ROCKWELL "C"

Material		Projection						Punch						Die			
Thickness T		Height H ± 2%		Diameter D ± 5%		Radius S		Radius R ± 0.13 [0.005]		Height P ± 2%		Hole Diameter d ± 0.13 [0.005]		Recess Radius r, r = S/3		Recess Height h, h, = H/3	
mm	[in]	mm	[in]	mm	[in]	mm	[in]	mm	[in]	mm	[in]	mm	[in]	mm	[in]	mm	[in]
3.12	[0.123]	1.47	[0.058]	6.86	[0.270]	4.98	[0.196]	2.39	[0.094]	1.91	[0.075]	5.61	[0.221]	1.65	[0.065]	0.48	[0.019]
3.43	[0.135]	1.57	[0.062]	7.62	[0.300]	5.46	[0.215]	2.77	[0.109]	2.06	[0.081]	6.35	[0.250]	1.83	[0.072]	0.51	[0.020]
3.89	[0.153]	1.63	[0.064	8.38	[0.330]	5.97	[0.235]	3.18	[0.125]	2.16	[0.085]	6.86	[0.270]	1.98	[0.078]	0.53	[0.021]
4.17	[0.164]	1.73	[0.068]	9.14	[0.360]	6.30	[0.248	3.58	[0.141]	2.31	[0.091]	7.54	[0.297]	2.11	[0.083]	0.58	[0.023]
4.55	[0.179]	2.03	[0.080]	9.91	[0.390]	6.96	[0.274]	3.96	[0.156]	2.64	[0.104]	8.33	[0.328]	2.31	[0.091]	0.69	[0.027]
4.95	[0.195]	2.13	[0.084]	10.41	[0.410]	7.26	[0.286]	3.96	[0.156]	2.82	[0.111]	8.59	[0.338]	2.41	[0.095]	0.71	[0.028]
5.33	[0.210]	2.29	[0.090]	11.18	[0.440]	7.75	[0.305]	4.75	[0.187]	3.05	[0.120]	9.09	[0.358]	2.57	[0.101]	0.76	[0.030]
5.72	[0.225]	2.54	[0.100]	11.94	[0.470]	8.26	[0.325]	4.75	[0.187]	3.35	[0.132]	9.35	[0.368]	2.74	[0.108]	0.84	[0.033]
6.22	[0.245]	2.84	[0.112]	13.46	[0.530]	9.27	[0.365]	4.75	[0.187]	3.71	[0.146]	10.31	[0.406]	3.07	[0.121]	0.94	[0.037]

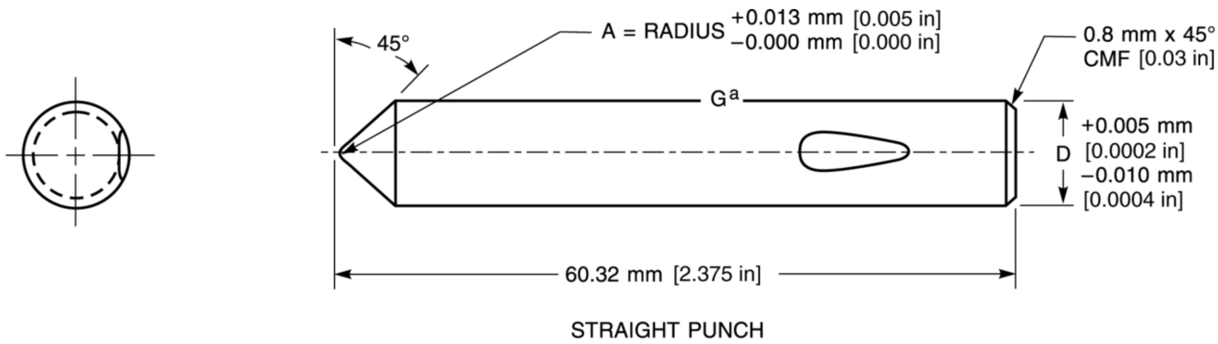
Table 38
Process Requirements for Projection Welding a Range of Heavy-Gauge Steels[a]

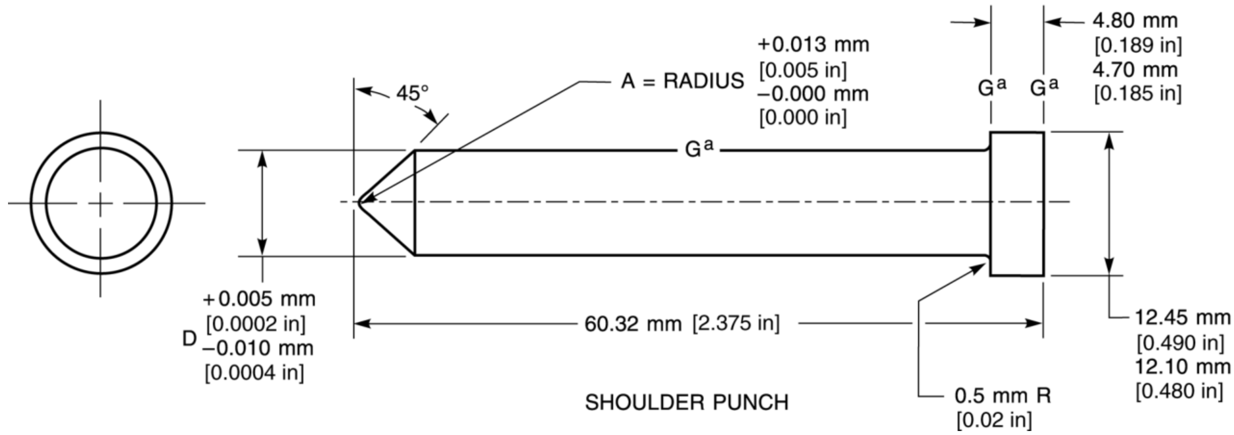
Of Low-Carbon[b] Steel[c]—3.89 to 6.22 mm [0.153 to 0.245 in] Thickness [Two Equal Thicknesses]

	Projection Size		Minimum							
Thickness mm [in]	Diameter mm [in]	Height mm [in]	Spacing to mm [in]	Contact Overlap mm [in]	Electrode[d] Force Weld kN [lb]	Electrode Force Forge kN [lb]	Up-slope[e] Time Cycles	Weld[e] Time Cycles	Welding[f] Current Amps	Tensile[g] Shear Strength kN [lb]
Schedule A—Welding Normal Size Welds										
3.89 [0.153]	8.38 [0.330]	1.57 [0.062]	44.4 [1.75]	23.0 [0.9]	8.9 [2000]	17.8 [4000]	15	60	15 400	33.4 [7 510]
4.17 [0.164]	8.89 [0.350]	1.73 [0.068]	45.7 [1.80]	24.1 [0.95]	10.2 [2300]	20.5 [4600]	15	70	16 100	36.0 [8 090]
7.05 [0.179]	9.91 [0.390]	2.03 [0.80]	48.3 [1.90]	25.4 [1.0]	11.7 [2630]	23.4 [5260]	20	82	17 400	42.3 [9 510]
4.95 [0.195]	10.41 [0.410]	2.13 [0.084]	50.8 [2.00]	26.7 [1.05]	13.0 [2930]	26.1 [5870]	20	98	18 800	50.3 [11 300]
5.33 [0.210]	11.18 [0.440]	2.34 [0.092]	53.3 [2.10]	29.2 [1.15]	14.2 [3180]	28.3 [6360]	25	112	20 200	55.6 [12 500]
5.72 [0.225]	11.94 [0.470]	2.54 [0.100]	33.01 [1.30]	30.5 [1.20]	16.1 [3610]	32.1 [7220]	25	126	21 500	66.7 [14 990]
6.22 [0.245]	13.46 [0.530]	2.84 [0.112]	63.5 [2.50]	33.0 [1.30]	17.4 [3900]	34.7 [7800]	30	145	23 300	7.70 [17 310]
Schedule B—Welding Small Size Welds										
3.89 [0.153]	6.86 [0.270]	1.47 [0.058]	40.6 [1.60]	19.0 [0.75]	6.2 [1400]	12.5 [2800]	15	60	11 100	22.7 [5 100]
4.17 [0.164]	7.37 [0.290]	1.57 [0.062]	41.9 [1.65]	20.3 [0.80]	6.3 [1430]	12.7 [2850]	15	70	11 800	24.5 [5.510]
7.05 [0.179]	7.87 [0.310]	1.70 [0.067]	43.2 [1.70]	21.6 [0.85]	6.7 [1500]	13.3 [3000]	20	82	12 800	28.9 [6 500]
4.95 [0.195]	8.38 [0.330]	1.83 [0.072]	44.4 [1.75]	22.9 [0.90]	7.1 [1600]	14.2 [3200]	20	98	13 900	34.3 [7 710]
5.33 [0.210	8.89 [0.350]	1.96 [0.077]	45.7 [1.80]	24.1 [0.95]	7.7 [1730]	15.4 [3460]	25	112	14 900	37.8 [8 500]
5.72 [0.225]	9.40 [0.370]	2.08 [0.082]	48.3 [1.90]	25.4 [1.00]	8.3 [1870]	16.6 [3740]	25	126	16 000	46.3 [10 410]
6.22 [0.245]	9.91 [0.390]	2.18 [0.088]	53.3 [2.10]	27.9 [1.10]	9.3 [2100]	18.7 [4200]	30	145	17 300	53.4 [12 000]

[a] Cycles per second or Hz can also be presented in ms [milliseconds].
[b] Low-carbon steel—SAE 1005–1010: 290–380 MPa (42–55 ksi) ultimate tensile strength.
[c] Surface of steel may be oiled lightly but free from grease, scale, and dirt.
[d] On single force welds use only weld force as electrode force. Electrode force contains no factor to further form poorly made parts.
[e] Based on AC 60 Hz equipment.
[f] Starting values shown are based on experience of member companies.
[g] Tensile-shear strength per projection depends on the joint design.

Table 39
Punch Design Data for Low-Carbon Steel Projections



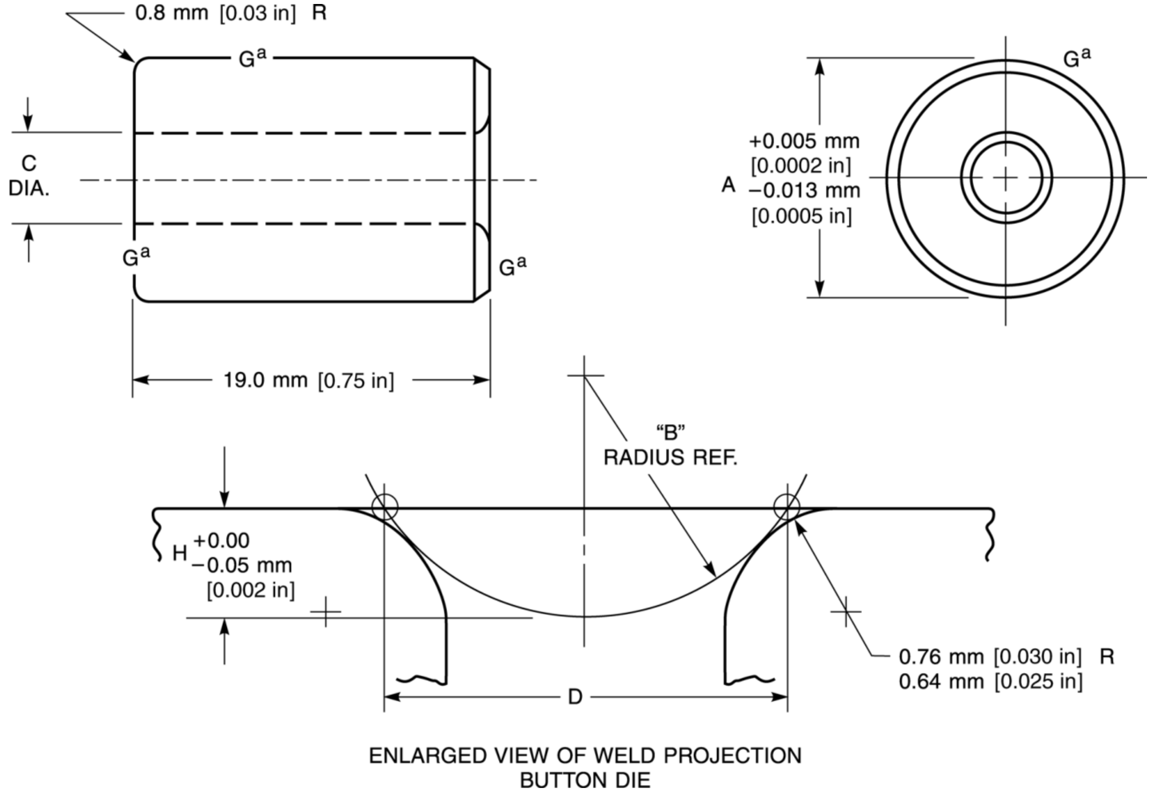


Sheet Thickness			A		D	
mm	[in]	Type of Punch	mm	[in]	mm	[in]
0.61–0.76	[0.024–0.032]	Straight, Shoulder	0.51	[0.020]	6.35	[0.250]
0.91–1.52	[0.036–0.060]	Straight, Shoulder	0.64	[0.025]	9.52	[0.375]
1.70–2.29	[0.067–0.090]	Straight, Shoulder	1.02	[0.040]	9.52	[0.375]

[a] G is ground surface.

Notes:
1. All dimensions are in mm [in].
2. The punches should be made from SAE M-2 steel, Hardness Rockwell “C” 60–63 and should be nitrided.
3. See Tables 42, 43, and 47 for projection sizes.
4. On straight punch, shank hardness should be 102–103 Rockwell “B.”

Table 40
Die Button Design Data for Low-Carbon Steel Projections

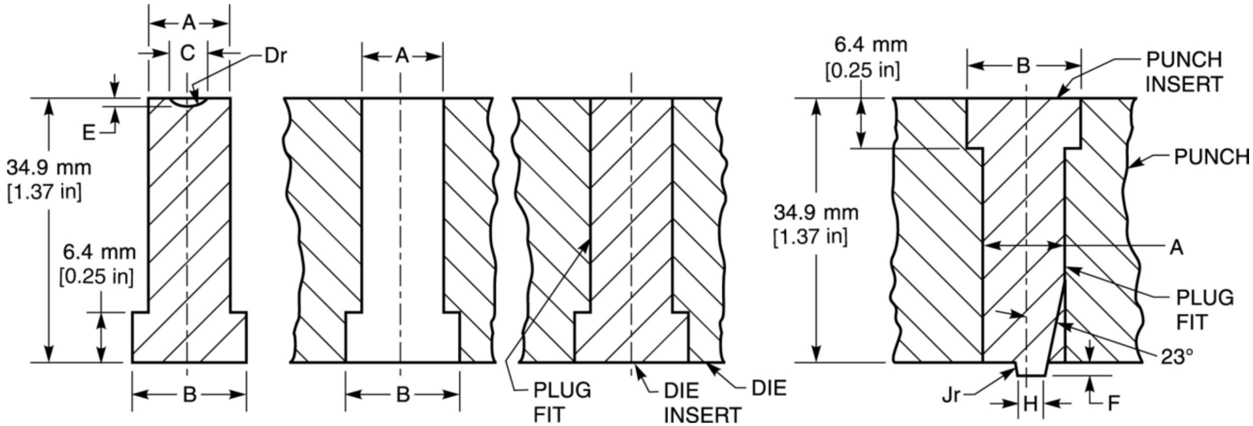


A		B Radius Ref.		C		D		H	
mm	[in]	mm	[in]	mm	[in]	mm	[in]	mm	[in]
9.53	[3.75]	1.30	[0.051]	1.70	[0.067]	2.29	[0.090]	0.69	[0.027]
9.53	[0.375]	1.52	[0.060]	2.08	[0.082]	2.67	[0.105]	0.81	[0.032]
9.53	[0.375]	1.73	[0.068]	2.44	[0.096]	3.05	[0.120]	0.94	[0.037]
12.70	[0.500]	2.03	[0.080]	2.95	[0.116]	3.56	[0.140]	1.07	[0.042]
12.70	[0.500]	2.34	[0.092]	3.25	[0.128]	4.06	[0.160]	1.19	[0.047]
12.70	[0.500]	2.64	[0.104]	3.91	[0.154]	4.57	[0.180]	1.32	[0.052]
15.88	[0.625]	3.20	[0.126]	4.70	[0.185]	5.33	[0.210]	1.45	[0.057]
15.88	[0.625[	3.58	[0.141]	4.85	[0.191]	6.10	[0.240]	1.70	[0.067]
15.88	[0.625]	4.22	[0.166]	6.53	[0.257]	7.37	[0.290]	1.96	[0.077]
15.88	[0.625]	4.85	[0.191]	7.49	[0.295]	8.13	[0.320]	2.21	[0.087]

[a] G is a ground surface.

Notes:
1. All dimensions are in mm [in].
2. The dies should be made from SAE A-2 steel, hardness Rockwell "C" 58–62.
3. See Tables 42, 43, and 47 for projection sizes, and Table 44 for punch design data.

Table 41
Punch and Die Design Data for Forming Projections on Stainless Steel[a, b]



		A	B	C		Dr		E		F		H		Jr	
Sheet Thickness mm [in]	Pt. No.	mm [in]	mm [in]	mm ± .05	[in ± .002]	mm	[in]	mm ± .03	[in ± .001]	mm ± .03	[in ± .001]	mm ± .03	[in ± .001]	mm	[in]
0.25–0.41 [0.012–0.016]	1	9.5 [0.37]	14.3 [0.56]	1.40	[0.055]	0.84	[0.033]	0.38	[0.015]	0.38	[0.015]	0.89	[0.035]	0.10	[0.004]
0.41–0.51 [0.016–0.020]	2	9.5 [0.37]	14.3 [0.56]	1.70	[0.067]	1.07	[0.042]	0.43	[0.017]	0.51	[0.020]	0.99	[0.039]	0.10	[0.004]
0.64 [0.025]	3	9.5 [0.37]	14.3 [0.56]	2.06	[0.081]	1.27	[0.050]	0.51	[0.020]	0.64	[0.025]	1.12	[0.044]	0.10	[0.004]
0.79 [0.031]	4	9.5 [0.37]	14.3 [0.56]	2.39	[0.094]	1.57	[0.062]	0.56	[0.022]	0.76	[0.030]	1.27	[0.050]	0.10	[0.004]
0.89 [0.035]	5	9.5 [0.37]	14.3 [0.56]	2.39	[0.094]	1.57	[0.062]	0.56	[0.022]	0.76	[0.030]	1.27	[0.050]	0.10	[0.004]
1.12 [0.044]	6	9.5 [0.37]	14.3 [0.56]	3.02	[0.119]	1.98	[0.078]	0.71	[0.028]	0.89	[0.035]	1.57	[0.062]	0.10	[0.004]
1.27 [0.050]	7	9.5 [0.37]	14.3 [0.56]	3.02	[0.119]	1.98	[0.078]	0.71	[0.028]	0.89	[0.035]	1.57	[0.062]	0.10	[0.004]
1.57 [0.062]	8	9.5 [0.37]	14.3 [0.56]	3.96	[0.156]	2.67	[0.105]	0.89	[0.035]	1.09	[0.043]	2.06	[0.081]	0.10	[0.004]
1.80 [0.071]	9	9.5 [0.37]	14.3 [0.56]	3.96	[0.156]	2.67	[0.105]	0.89	[0.035]	1.09	[0.043]	2.06	[0.081]	0.10	[0.004]
1.98 [0.078]	10	9.5 [0.37]	14.3 [0.56]	4.75	[0.187]	3.25	[0.128]	1.04	[0.041]	1.40	[0.055]	2.64	[1.04]	0.28	[0.011]
2.39 [0.094]	11	12.7 [0.50]	17.5 [0.69]	5.54	[0.218]	3.76	[0.148]	1.22	[0.048]	1.65	[0.065]	2.92	[0.115]	0.28	[0.011]
2.77 [0.109]	12	12.7 [0.50]	17.5 [0.69]	6.35	[0.250]	4.37	[0.172]	1.37	[0.054]	1.91	[0.075]	3.48	[0.137]	0.40	[0.016]
3.18 [0.125]	13	12.7 [0.50]	17.5 [0.69]	7.14	[0.281]	4.90	[0.193]	1.52	[0.060]	2.16	[0.085]	3.91	[0.154]	0.40	[0.016]
3.56 [0.140]	14	12.7 [0.50]	17.5 [0.69]	7.92	[0.312]	5.51	[0.217]	1.68	[0.066]	2.44	[0.096]	4.37	[0.172]	0.40	[0.016]
3.96 [0.156]	15	15.9 [0.63]	20.6 [0.81]	8.71	[0.343]	6.17	[0.243]	1.83	[0.072]	2.72	[0.107]	4.85	[0.191]	0.40	[0.016]
4.34 [0.171]	16	15.9 [0.63]	20.6 [0.81]	9.53	[0.375]	6.73	[0.265]	1.98	[0.078]	3.00	[0.118]	5.33	[0.210]	0.40	[0.016]
4.75 [0.187]	17	15.9 [0.63]	20.6 [0.81]	10.31	[0.406]	7.24	[0.285]	2.16	[0.085]	3.30	[0.130]	5.82	[0.229]	0.40	[0.016]
5.16 [0.203]	18	17.5 [0.69]	22.2 [0.87]	11.10	[0.437]	7.82	[0.308]	2.31	[0.091]	3.63	[0.143]	6.10	[0.240]	0.51	[0.020]
6.35 [0.250]	19	20.6 [0.81]	25.4 [1.00]	13.49	[0.531]	9.53	[0.375]	2.79	[0.110]	4.45	[0.175]	7.24	[0.285]	0.64	[0.025]

[a] Make die and punch inserts from air-hardening chrome-vanadium steel. Finish all over and harden to 65–68 Rockwell “C” scale.
[b] Polish all working surfaces of die unit surface. all working surfaces of die unit must be polished.

Table 42
Projection Welding Parameters for Low-Carbon Steel[a]

Stock Thickness mm [in]	Projection Size Diameter mm [in]	Projection Size Height mm [in]	Net Electrode Force kN [lb]	Welding Time Cycles[b]	Welding Current Amps Low	Welding Current Amps High	Minimum Spacing[c] mm [in]	Minimum Shear Strength kN [lb]
0.51–0.71 [0.020–0.028]	2.67 [0.105]	0.76 [0.030]	0.67 [150]	3–4	3 000	5 000	9.6 [0.38]	2.67 [600]
0.79–0.91 [0.031–0.036]	3.05 [0.120]	0.89 [0.035]	0.89 [200]	4	4 000	6 000	12.7 [0.50]	4.67 [1050]
0.94–1.22 [0.037–0.048]	3.56 [0.140]	1.02 [0.040]	1.33 [300]	5	5 000	7 500	19.0 [0.75]	5.78 [1300]
1.27–1.55 [0.050–0.061]	4.06 [0.160]	1.14 [0.045]	2.00 [450]	7	6 500	9 500	19.0 [0.75]	8.01 [1800]
1.57–2.03 [0.062–0.080]	4.57 [0.180]	1.27 [0.050]	2.89 [650]	10	7 500	11 000	22.4 [0.88]	10.79 [2430]
2.08–2.44 [0.082–0.096]	5.33 [0.210]	1.40 [0.055]	4.00 [900]	13	9 000	13 000	26.9 [1.06]	14.46 [3250]
2.54–3.10 [0.100–0.122]	6.10 [0.240]	1.65 [0.065]	4.96 [1150]	16	10 000	14 500	31.8 [1.25]	17.13 [3850]
3.18–3.81 [0.125–0.150]	7.11 [0.280]	1.90 [0.075]	6.01 [1350]	19	11 500	16 500	38.1 [1.50]	21.35 [4800]

[a] This table is to be used in conjunction with Table 47 which gives the sheet thickness combinations that correspond to the projection sizes shown.
[b] Based on single-phase AC 60 Hz equipment.
[c] Minimum weld spacing is measured from centerline to centerline.

Notes:
1. Electrodes: RWMA Class 2, truncated cone shape with 20-degree bevel and face diameter of 3 times the projection diameter.
2. For multiple projection welding, multiply the force and current by the number of projections to be welded but keep the welding time constant
3. Cycles per second or Hz can also be presented in ms [milliseconds].

Table 43
Projection Welding Parameters for Galvanized Low-Carbon Steel[a,b]

Material Thickness mm [in]	Electrode[c,d] Body Diameter mm [in]	Electrode[c,d] Face Diameter mm [in]	Net Electrode Force kN [lb]	Welding Current Amps	Welding Time Cycles	Satisfactory Nugget Diameter mm [in]	Projection Size Diameter mm [in]	Projection Size Height mm [in]	Minimum Tension-Shear Strength kN [lb]
0.99 [0.039]	15.88 [0.625]	9.52 [0.375]	1.11 [250]	10 000	15	3.8 [0.15]	4.75 [0.187]	1.04 [0.041]	4.11 [920]
1.35 [0.053]	15.88 [0.625]	11.13 [0.438]	1.78 [400]	11 500	20	6.4 [0.25]	5.54 [0.218]	1.22 [0.048]	9.12 [2050]
1.98 [0.078]	19.05 [0.750]	12.70 [0.500]	2.45 [550]	16 000	25	6.4 [0.25]	6.35 [0.250]	1.37 [0.054]	12.01 [2700]
2.36 [0.093]	19.05 [0.750]	12.70 [0.500]	3.34 [750]	16 000	30	7.6 [0.30]	6.35 [0.250]	1.37 [0.054]	19.13 [4300]
2.77 [0.109]	22.22 [0.875]	12.70 [0.500]	4.23 [950]	22 000	33	7.9 [0.31]	6.35 [0.250]	1.37 [0.054]	21.80 [4900]

[a] Welding parameters are applicable for projection welding galvanized low-carbon steel.
[b] Cycles per second or Hz can also be presented in ms [milliseconds].
[c] Welding parameters are applicable using electrode materials included in RWMA Classes 1, 2, and 20.
[d] The welding electrode design that the above parameters apply to include a flat face with a 20-degree bevel.

5.3 Solid Projection Welding

5.3.1 Projection Design and Welding Parameters

5.3.1.1 Fastener Welding. Assorted nuts and fasteners can be successfully mounted to intermediate and heavy-gauge sheets using projection welding. The process can also be used with thinner gauge sheets, but more care is required in preventing distortion to the thinner sheet due to projection penetration. Uniformity in projection contact with the opposing surface when the electrode force is applied is critical, regardless of the number of projections on the fastener (nut). Such projections are normally scaled according to the sheet being joined as indicated in Table 47.

5.3.1.2 Cross-Wire Welding. In cross-wire welding, the localization of the welding current and force is achieved by the contact of intersecting wires and there is generally substantial upset. Process conditions for cross-wire welding are shown in Table 48 for a range of wire thicknesses. Welding conditions are usually specified in terms of the requirements for achieving a certain level of set-down (or collapse) for the wires. Set-down is defined in Figure 28. As the percentage

Table 44
Projection Welding Parameters for Stainless Steels[a,b]

Sheet Thickness mm [in]	Electrode Face Diameter[c] [2 Times Proj. Diameter] 20° Bevel mm [in]	Net Electrode Force kN [lb]	Weld Time Cycles	Hold Time Cycles	Welding Current [at Electrodes] 60 Cycles A-C [Approx.] Amps
0.36 [0.014]	3.2 [0.13]	1.3 [300]	7	15	4 500
0.53 [0.021]	4.0 [0.16]	2.2 [500]	10	15	4 750
0.79 [0.031]	4.8 [0.19]	3.1 [700]	15	15	5 750
1.12 [0.044]	6.4 [0.25]	3.1 [700]	20	15	6 000
1.57 [0.062]	7.9 [0.31]	5.3 [1200]	25	15	7 500
1.98 [0.078]	9.5 [0.37]	8.5 [1900]	30	30	10 000
2.39 [0.094]	11.1 [0.44]	8.5 [1900]	30	30	10 000
2.77 [0.109]	12.7 [0.50]	12.5 [2800]	30	45	13 000
3.18 [0.125]	14.3 [0.56]	12.5 [2800]	30	45	14 000

[a] Types of Steel: 309, 310, 316, 317, 321, 347, and 349.
[b] Cycles per second or Hz can also be presented in ms [milliseconds].
[c] Electrode material: RWMA Class 2, 3, or 12.

Table 45
Projection Designs and Process Requirements for Annular Projection Welding Some Representative Light-Gauge Steels[c]

Projection Welding of Low-Carbon[a] Steel[b]
0.28 mm to 0.48 mm [0.011 in to 0.019 in] Thickness [Two Equal Thicknesses]

Thickness mm [in]	Minimum Spacing mm [in]	Minimum Contact Overlap mm [in]	Weld[d] Time Cycles	Electrode[e] Force kN [lb]	Welding[f] Current Amps	Tensile-Shear Strength[g] Each Projection	
						One kN [lb]	Two or More kN [lb]
0.28 [0.011]	7.9 [0.31]	6.4 [0.25]	6	0.50 [110]	5200	0.85 [190]	0.65 [145]
0.48 [0.019]	7.9 [0.31]	6.4 [0.25]	6	1.00 [225]	5400	1.78 [400]	1.25 [280]

[a] Low-carbon steel—SAE 1010–290–380 MPa [42–55 ksi] ultimate tensile strength.
[b] Surface of steel may be oiled lightly but free from grease, scale, and dirt.
[c] Cycles per second or Hz can also be presented in ms [milliseconds].
[d] Based on 60 Hz.
[e] Electrode force contains no factor to further form poorly made parts.
[f] Starting values shown are based on experience of member companies.
[g] Approximate strength per projection—depends on joint design.

of set-down increases (up to 50 percent), the joint strength increases as more bond area is established. The process conditions defined are for mild steels. Higher strength materials, such as stainless and nickel-based alloys, will require higher forces and longer welding times to promote the wire collapse and fusion.

5.3.1.3 Annular Projection Welding. Specific projection design and process conditions for annular projection welding are not uniformly established. There is general consensus on the use of 90 degree included angle triangular cross-section projections scaled to the thickness of the opposing sheet. An annular relief groove may also be required to provide an outlet for material in the projection that is forged or extruded during welding. Typical practices use linear force (ratio electrode force/length of projection) of 175–350 N/mm [1000–2000 lbf/in]. Weld times for diameters of 6.4–25 mm [0.25–1.00 in] usually range from one to ten cycles.

Annular projections are normally offset from the outer periphery of the part. Projection designs which extend to the outside of the part have the potential of unstable projection collapse. This can result in formation of notches or bulges at the joint. This is illustrated in Figure 29.

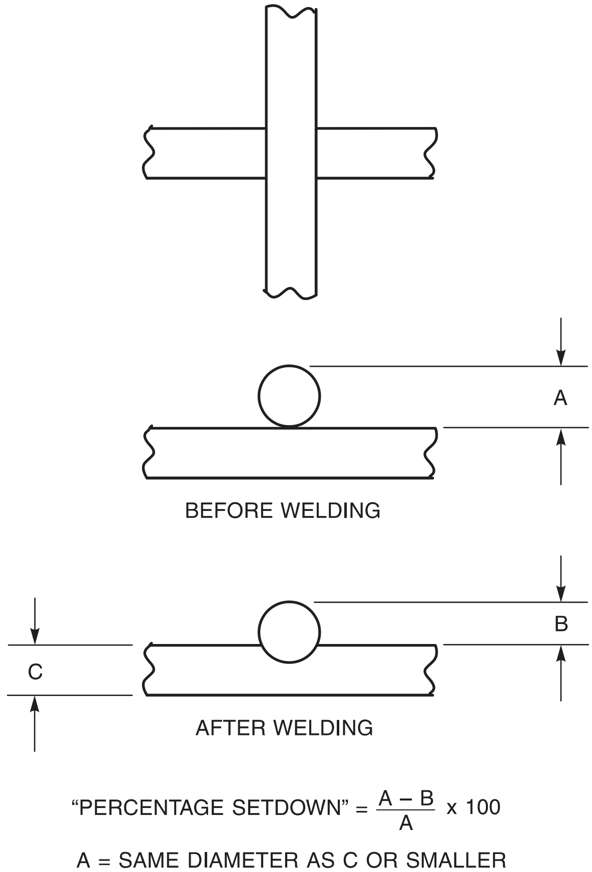


Figure 28—Diagram Defining How Set-Down is Estimated on Cross-Wire Welds

When larger diameter annular projection welds are made, there may be problems encountered in achieving proper heat balance around the entire periphery of the projection. Direct current machines or optimized transformer arrangements may be required to overcome such problems.

5.4 Multiple Projection Welding. Multiple projections require additional care in electrode design to assure that the electrode contacts the workpiece and provides uniform current distribution to all projections. It is normally recommended that the electrode contact face be at least twice the diameter of the projection pattern. Welding conditions are normally proportionally the same as those shown in the tables for single projection welds. Weld force and welding current for the first projection should be added to 50% of force and current for each additional projection. The welding time, however, remains the same as for single projection welding.

5.5 Weld Quality and Mechanical Property Tests. Tests for resistance spot welds can be applied for projection welds. However, some modifications may be required due to workpiece geometry or dissimilarity in metal thicknesses joined. Projection weld-quality tests commonly reflect the weld application requirements. Fasteners, including nuts and studs are generally tested in tension or by measuring torque. The tensile load can be applied to push or pull the fastener off. The bend test frequently applied for arc welded studs is not common for smaller resistance welding studs.

6. Flash Welding

6.1 Introduction. Flash welding (FW) is a resistance welding process producing a weld at the faying surfaces of a butt joint by flashing action and by the application of pressure after heating is substantially completed. The flashing action, caused by the very high current densities at small contact point between the workpieces, forcibly expels the material from

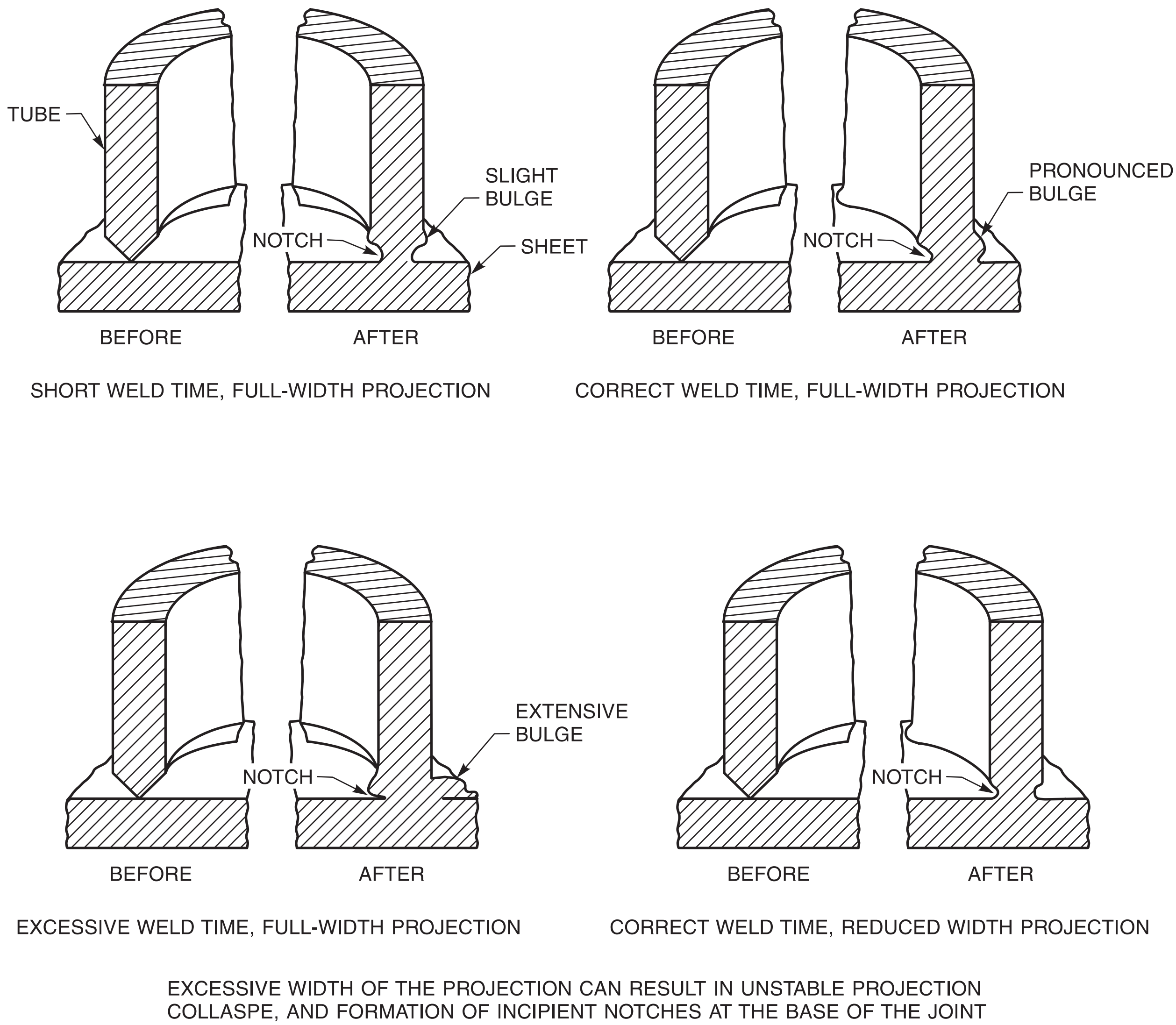


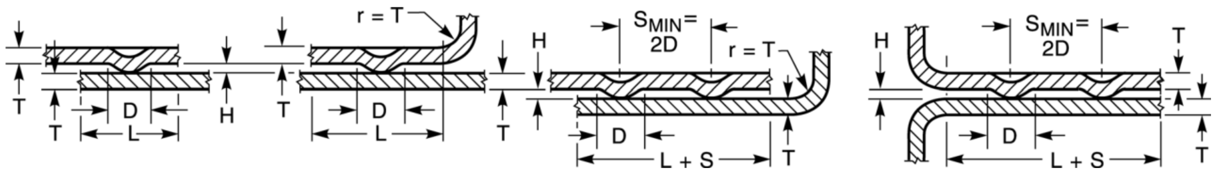
Figure 29—Characteristics of Projection Collapse during Annular Projection Welding with Different Base-Projection Widths

the joint as the workpieces are slowly moved together. The weld is completed by a rapid upsetting of the workpieces. The pieces to be welded similar in shape and cross section, in a butt joint and are clamped in current conducting dies which form part of the electrical circuit of the machine. Light contact is made between the pieces, and a high current is established through the circuit, causing local points of contact to be heated beyond the melting point.

Proper flashing action is maintained by moving the work together at a controlled rate. When the surfaces to be joined become sufficiently plastic, they are rapidly forged together under high force, displacing the hot metal in the form of an upset. The molten metal is expelled resulting in a solid-state joint. This upset action, in addition to producing the weld, closes all craters formed during flashing and expels oxides and impurities from the weld.

6.2 Equipment. Welding equipment varies in the methods used to conduct the welding current and apply the welding force to the workpiece. All equipment must be capable of bringing the workpieces together in a controlled manner and automatically regulating the feed of the workpieces (rate and distance of travel), the secondary voltage and current, and the timing of the application of current and upset force.

Table 46
Projection Welding Design Data for Stainless Steels[a, b,c]



Thickness T of Thinnest outside Piece [Nominal][a,b,d,e] mm [in]	Diameter of Projection D[f,g,h] below] mm [in]	Height of Projection H[f,g,i] below] mm [in]	Minimum Shear Strength [Single Projections Only] kN [lb]			Minimum Nugget Diameter [at Weld Interface] mm [in]	Minimum Contacting Overlap[j,k] mm [in]
			Tensile Strenght Below 480 MPa [70 ksi]	Tensile Strength 480 MPa [70 ksi] Up to 1.03 GPa [150 ksi]	Tensile Strenght 1.03 GPa [150 ksi] and Above		
0.25 [0.010]	1.40 [0.055]	0.38 [0.015]	0.57 [130]	0.80 [180]	1.11 [250]	2.48 [0.112]	3.2 [0.13]
0.30[0.012]	1.40 [0.055]	0.38 [0.015]	0.76 [170]	0.98 [220]	1.47 [330]	2.48 [0.112]	3.2 [0.13]
0.36 [0.014]	1.40 [0.055]	0.38 [0.015]	0.89 [200]	1.25 [280]	1.69 [380]	2.48 [0.112]	3.2 [0.13]
0.41 [0.016]	1.70 [0.067]	0.43 [0.017]	1.07 [240]	1.47 [330]	2.00 [450]	2.48 [0.112]	4.0 [0.16]
0.53 [0.021]	1.70 [0.067]	0.43 [0.017]	1.42 [320]	1.96 [440]	2.67 [600]	3.56 [0.140]	4.0 [0.16]
0.64 [0.025]	2.06 [0.081]	0.51 [0.020]	2.00 [450]	2.67 [600]	3.65 [820]	3.56 [0.140]	4.8 [0.19]
0.79 [0.031]	2.39 [0.094]	0.56 [0.022]	2.82 [630]	3.78 [850]	4.89 [1100]	4.29 [0.169]	5.6 [0.22]
0.86 [0.034]	2.39 [0.094]	0.56 [0.022]	3.51 [790]	4.45 [1000]	5.78 [1300]	4.29 [0.169]	5.6 [0.22]
1.12 [0.044]	3.02 [0.119]	0.71 [0.028]	4.09 [920]	5.78 [1300]	8.90 [2000]	4.29 [0.169]	7.1 [0.28]
1.27 [0.050]	3.02 [0.119]	0.71 [0.028]	6.01 [1 350]	7.56 [1700]	10.68 [2400]	5.72 [0.225]	7.1 [0.28]
1.57 [0.062]	3.96 [0.156]	0.89 [0.035]	8.67 [1 950]	10.01 [2250]	15.12 [3400]	5.72 [0.225]	9.5 [0.37]
1.78 [0.070]	3.96 [0.156]	0.89 [0.035]	10.23 [2 300]	12.45 [2800]	18.68 [4200]	7.14 [0.281]	9.5 [0.37]
1.98 [0.078]	4.75 [0.187]	1.04 [0.041]	12.01 [2 700]	1.42 [3200]	21.35 [4800]	7.14 [0.281]	11.1 [0.44]
2.39 [0.094]	5.54 [0.218]	1.22 [0.048]	15.34 [3 450]	17.79 [4000]	27.13 [6100]	7.14 [0.281]	12.7 [0.50]
2.77 [0.109]	6.35 [0.250]	1.37 [0.054]	18.46 [4 150]	22.24 [5000]	31.14 [7000]	8.59 [0.338]	16.0 [0.63]
3.18 [0.125]	7.14 [0.281]	1.60 [0.060]	21.35 [4 800]	25.35 [5700]	35.59 [8000]	8.59 [0.338]	17.5 [0.69]
3.56 [0.140]	7.92 [0.312]	1.67 [0.066]	26.69 [6 000	— —	— —	11.1 [0.44]	19.0 [0.75]
3.96 [0.156]	8.71 [0.343]	1.83 [0.072]	33.36 [7 500	— —	— —	12.7 [0.50]	20.6 [0.81]
4.34 [0.171]	9.52 [0.375]	1.98 [0.078]	37.81 [8 500]	— —	— —	14.3 [0.56]	22.2 [0.87]
4.75 [0.187]	10.31 [0.406]	2.16 [0.085]	44.48 [10 000]	— —	— —	14.3 [0.56]	23.8 [0.94]
5.16 [0.203]	11.10 [0.437]	2.31 [0.091]	53.38 [12 000]	— —	— —	16. 0[0.63]	25.4 [1.00]
6.35 [0.250]	13.49 [0.531]	2.79 [0.110]	66.72 [15 000	— —	— —	17.5 [0.69]	31.8 [1.25]

[a] Stainless steel types: 309, 310, 316, 317, 321, 347, and 349.
[b] Material should be free from scale, oxides, paint, grease, and oil.
[c] Cycles per second or Hz can also be presented in ms [milliseconds].
[d] Size of projection normally determined by thickness of thinner piece, and projection should be on thicker piece where possible.
[e] Data based on thickness of thinner sheet, and for two thickness only.
[f] Projection should be made on piece of higher conductivity when dissimilar metals are welded.
[g] For diameter of Projection D a tolerance of ±0.08 mm [±0.003 in] in material up to and including 1.27 mm including 1.27 mm [0.050 in] in thickness and ±0.20 nun [±0.008 in] in material over 1.27 mm [0.050 in] in thickness may bee allowed.
[h] See Table 41 for data on punch and die designs for making projections.
[i] For weight of Projection H a tolerance of ±0.05 [±0.002 in] in material up to and including 1.27 mm [0.050 in] in thickness and ±0.13 mm [±0.005 in] in material over 1.27 mm [0.050 in] in thickness may be allowed.
[j] Contacting overlap does not include any radi from forming, etc.
[k] Weld should be located in center of overlap.

Table 47
Embossed Projection Dimensions for Low-Carbon Steel

Nom. Thick. mm [in]	Min. Thick. mm [in]		METAL THICKNESS IN WHICH PROJECTION WILL BE FORMED																		
			4.32 [0.170]	3.81 [0.150]	3.56 [0.140]	3.10 [0.122]	2.92 [0.115]	2.74 [0.108]	2.44 [0.096]	2.08 [0.082]	1.73 [0.068]	1.55 [0.061]	1.37 [0.054]	1.22 [0.048]	1.09 [0.043]	0.91 [0.036]	0.79 [0.031]	0.71 [0.028]	0.66 [0.026]	0.56 [0.022]	0.51 [0.020]
0.61 [0.024]	0.51 [0.020]	D H																			
0.71 [0.028]	0.56 [0.022]	D H	ZONE 1 D=4.57 [0.180] H=1.27 [0.050]				ZONE 7 D=3.56 [0.140] H=1.02 [0.040]				ZONE 8 D=3.05 [0.120] H=0.89 [0.035]					ZONE 9 D=2.67 [0.150] H=0.76 [0.030]					
0.76 [0.030]	0.66 [0.026]	D H																			
0.81 [0.032]	0.71 [0.028]	D H																			
0.91 [0.036]	0.79 [0.031]	D H																			
1.07 [0.042]	0.91 [0.036]	D H																			
1.22 [0.048]	1.09 [0.043]	D H																			
1.35 [0.053]	1.22 [0.048]	D H																			
1.52 [0.060]	1.37 [0.054]	D H																			
1.70 [0.067]	1.55 [0.061]	D H		ZONE 2 D=4.06 [0.160] H=1.14 [0.045]																	
1.91 [0.075]	1.73 [0.068]	D H																			
2.29 [0.090]	2.08 [0.082]	D H					ZONE 3 D=5.33 [0.210] H=1.40 [0.055]														
2.69 [0.160]	2.44 [0.096]	D H																			
3.00 [0.118]	2.74 [0.108]	D H																			
3.18 [0.125]	2.92 [0.115]	D H			ZONE 4 D=6.10 [0.240] H=1.65 [0.065]																
3.35 [0.132]	3.10 [0.122]	D H																			
3.81 [0.150]	3.56 [0.140]	D H		ZONE 5 D=7.11[0.280] H=1.91[0.075]																	
4.06 [0.160]	3.81 [0.150]	D H																			
4.57 [0.180]	4.32 [0.170]	D H	ZONE 6 D=8.13/[0.320] H=2.16/[0.085]																		

Notes:
1. For each zone, the diameter 'D' and the height 'H' are common for the entire zone.
2. See Table 39 for punch design data, Tables 40 and 41 for die design data, and Tables 42, 43, and 44 for weld schedules.
3. When the thickness ratio of the pieces to be welded is 4-to-1 or greater, the projections should be on the thicker piece.
4. See RWMA for additional information on heavier guage material.

Table 48
Process Requirements for Cross-Wire Welding a Range of Thicknesses of Hot- and Cold-Drawn Steel Wires

Tabulated Strengths of Cross-Wire Welds For Specified Percentages of Setdown

	Cold-Drawn Wire				Hot-Drawn Wire			
Wire Diameter mm [in]	Weld Time Cycles	Weld Force kN [lb]	Welding Current Amps	Weld Strength kN [lb]	Weld Time Cycles	Weld Force kN [lb]	Welding Current Amps	Weld Strength kN [lb]
15 Percent Setdown								
1.6 [0.06]	5	0.44 [100]	600	2.00 [450]	5	0.44 [100]	600	1.56 [350]
3.2 [0.13]	10	0.56 [130]	1 800	4.34 [980]	10	0.56 [130]	1 850	3.34 [750]
4.8 [0.19]	17	1.60 [360]	3 300	8.90 [2 000]	17	1.60 [360]	3 500	6.67 [1 500]
6.4 [0.25]	23	2.56 [580]	4 500	16.46 [3 700]	23	3.36 [580]	4 900	12.46 [2 800]
7.9 [0.31]	30	3.67 [830]	6 000	22.69 [5 100]	30	3.67 [830]	6 600	20.46 [4 600]
9.5 [0.37]	40	4.89 [1100]	7 000	29.80 [6 700]	40	4.89 [1100]	7 700	27.59 [6 200]
11.1 [0.44]	50	6.23 [1400]	9 300	42.70 [9 600]	50	6.23 [1400]	10 000	39.14 [8 800]
12.7 [0.50]	60	7.56 [1700]	10 300	54.27 [12 000]	60	7.56 [1700]	11 000	51.15 [11 500]
30 Percent Setdown								
1.6 [0.06]	5	0.67 [150]	800	2.22 [500]	5	0.67 [150]	800	1.78 [400]
3.2 [0.13]	10	1.16 [260]	2 650	5.00 [1 120]	10	1.16 [260]	2 770	3.78 [850]
4.8 [0.19]	17	2.67 [600]	5 000	10.68 [2 400]	17	2.67 [600]	5 100	7.56 [1 700]
6.4 [0.25]	23	3.78 [850]	6 700	18.68 [4 200]	23	3.78 [850]	7 100	13.34 [3 000]
7.9 [0.31]	30	6.45 [1450]	9 300	27.13 [6 100]	30	6.45 [1450]	9 600	22.24 [5 000]
9.5 [0.37]	40	9.16 [2060]	11 300	37.81 [8 500	40	9.16 [2060]	11 800	30.25 [6 800]
11.1 [0.44]	50	12.90 [2900]	13 800	48.93 [11 000]	50	12.90 [2900]	14 000	42.70 [9 600]
12.7 [0.50]	60	15.12 [3400]	15 800	60.50 [13 600]	60	15.12 [3400]	16 500	55.16 [12 400]
50 Percent Setdown								
1.6 [0.06]	5	0.89 [200]	1 000	2.45 [550]	5	0.89 [200]	1 000	2.00 [450]
3.2 [0.13]	10	1.56 [350]	3 400	5.56 [1 250]	10	1.56 [350]	3 500	4.00 [900]
4.8 [0.19]	17	3.34 [750]	6 000	11.12 [2 500]	17	3.34 [750]	6 300	8.00 [1 800]
6.4 [2.25]	23	5.52 [1240]	8 600	19.57 [4 400]	23	5.52 [1240]	9 000	13.79 [3 100]
7.9 [0.31]	30	8.90 [2000]	11 400	28.91 [6 500]	30	8.90 [2000]	12 000	23.58 [5 300]
9.5 [0.37]	40	13.34 [3000]	14 400	39.14 [8 800]	40	13.34 [3000]	14 900	32.03 [7 200]
11.1 [0.44]	50	19.79 [4450]	17 400	52.93 [11 900]	50	19.79 [4450]	18 000	45.37 [10 200]
12.7 [0.50]	60	22.24 [5000]	21 000	64.94 [14 600]	60	23.58 [5300]	22 000	57.83 [13 000]

Notes:
1. Starting values shown are based on experience of member companies.
2. Cycles per second or Hz can also be presented in ms [milliseconds].

6.2.1 Platen Feed. The platens must be advanced toward each other in order to maintain flashing. Manual flashing should be restricted to less than 15 percent of the total flash time. Automatic flash feed may be affected by cam followers, servo motor drives, hydraulic actuators, or pneumatic controls. A constant acceleration will provide increased heating with reduced material loss.

6.2.2 Secondary Voltage and Current. The peak secondary voltage during flash time may be controlled by means of taps on the welding transformer. While phase shift controls can regulate current during upset or postheat, they have limited ability to control flashing voltage and current. Therefore, proper physical setting of the transformer tap ratio is necessary to establish a functional operating point for the process. Properly applied inverter controls, however, are not subject to these limitations and can effectively manage voltage and current during all parts of the flash welding process. This reduces the dependence on tap adjustments to balance the voltage and current needed to achieve robust flashing.

6.2.3 Timing. Upset current and force timing may be controlled by means of cams, limit switches, or electronic controls. Flash time is to be controlled by the platen feed system.

6.2.4 Electrodes. The electrodes should be of adequate size and should be so fitted to the surfaces of the workpieces to be welded that alignment of the workpiece cross section is properly maintained and the necessary current will be uniformly distributed about the contact surfaces. The electrode material should be capable of conducting current to the workpieces without damage due to localized overheating.

6.3 Welding Variables. Flash welding involves a large number of variables. These variables are listed and defined here along with a variable definition chart (see Figures 30 and 31) It should be realized that not all equipment nor all welding schedules can use all of these variables.

automatic flash-loss (F, mm [in]) is the length of material that is consumed in flashing while the flashing is controlled automatically.

average rate of flash-loss (m/s [in/s]) is the average velocity of one workpiece relative to the other during the entire flashing action.

average velocity of upset (m/s [in/s]) is the average velocity of one workpiece relative to the other during the entire upsetting action.

automatic flash time (s) is the time during which flashing by automatic control is taking place.

clamp force (newton [lbf]) is the force exerted on the dies by the clamping system.

clamp-holding time (s) is the time measured from the end of postheat time (or end of upsetting time when no postheat is used) to the time when the clamping force is released from the workpieces.

final extension, material X (N, mm [in]) is the dimension from the die which clamps Material X to the Weld Line at the completion of the weld.

final extension, material Y (P, mm [in]) is the dimension from the die which clamps Material Y to the Weld Line at the completion of the weld.

final fixture opening (C, mm [in]) is the distance between the upper and lower fixture at the completion of the weld.

flash is the material that is expelled from a flash weld prior to the upset portion of the welding cycle.

flash current (rms. A) is the total rms current impulse or series of impulses that occur through the workpieces during flashing.

flash time (s) is the duration of flashing action during flash welding.

flash voltage (rms. V) is the total rms voltage that occurs across the workpieces during flashing.

initial extension, material X (L, mm [in]) is the dimension from the die which clamps Material X to that point on Material X which first contacts Material Y.

initial extension, material Y (M, mm [in]) is the dimension from the die which clamps Material Y to that point on Material Y which first contacts Material X.

initial fixture opening (A, mm [in]) is the distance between the upper and lower fixture when the workpieces first make contact.

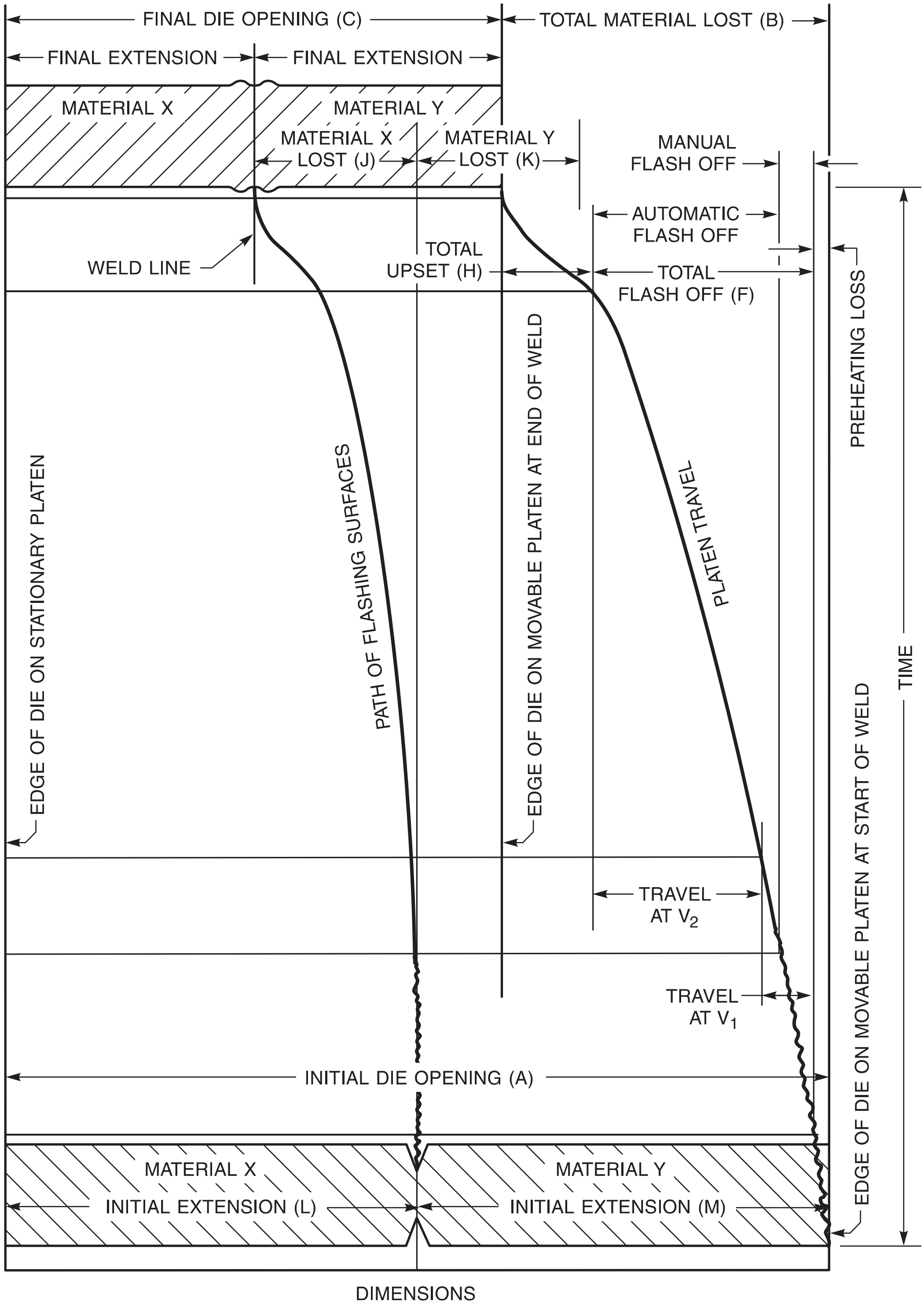


Figure 30—Chart of Flash Welding Definitions

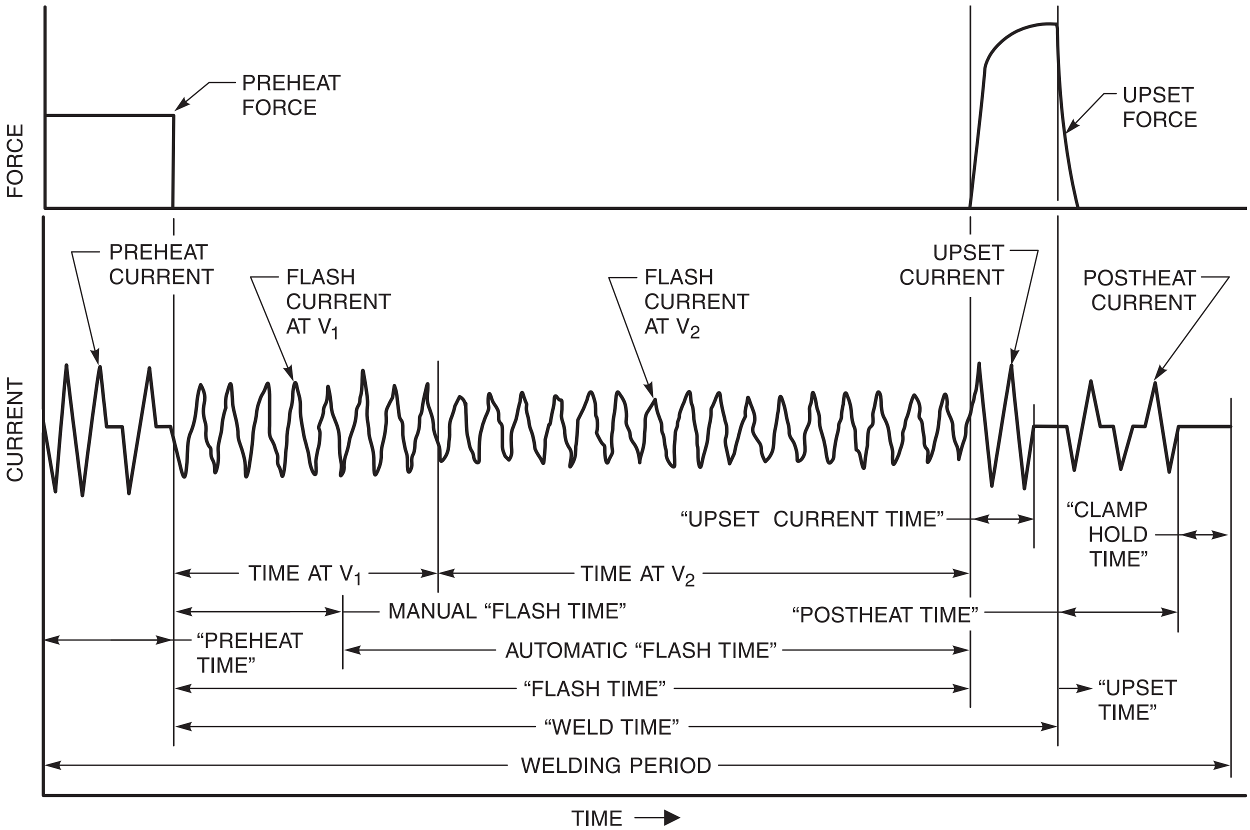


Figure 31—Chart of Flash Welding Definitions

instantaneous rate of flash-loss (m/s [in/s]) is the instantaneous velocity of one workpiece relative to the other during flashing action and is the first derivative of such motion at a specified position.

instantaneous velocity of upset (m/s [in/s]) is the instantaneous velocity of one workpiece relative to the other during upsetting action and is the first derivative of such motion at a specified position.

material loss (B, mm [in]) is the total length of material that is consumed in making the weld.

manual flash-loss (E, mm [in]) is the length of material that is consumed in flashing while the flashing is controlled manually.

manual flash time (s) is the time during which flashing by manual control is taking place.

material X loss (J, mm [in]) is the length of Material X that is consumed in making the weld.

material Y loss (K, mm [in]) is the length of Material Y that is consumed in making the weld.

platen force (newton [lbf]) is the force available at the movable platen to cause upsetting. This force may be dynamic, theoretical, or static.

postheat current (rms. A) is the total rms current impulse or series of impulses that occur through the workpieces during postheating.

postheat time (s) is the time during which postheating is taking place.

postheat voltage (rms. V) is the total rms voltage that occurs across the workpieces during postheating.

preheat current (rms. A) is the total rms current impulse or series of impulses that occur prior to initiation of flash current.

preheat voltage (rms. V) is the total rms voltage that occurs across the workpieces prior to initiation of flash current.

preheat loss (G, mm [in]) is the length of material that is consumed as a result of the preheating action.

preheat force (newton [lbf]) is the force exerted on the welding surfaces during preheating.

preheat time (s) is the duration of preheat current flow during the preweld interval.

secondary voltage (rms. V) is the open-circuit voltage of the welding transformer measured on the secondary side with no phase shift.

spring-back (mm) [in]) is the deflection of the welding machine when making the weld.

time at flash current I_1 (s) is the time during which flashing with current I_1 is taking place.

time at flash current I_2 (s) is the time during which flashing with current I_2 is taking place.

total flash-loss (D, mm [in]) is the total length of material that is consumed in flashing.

total upset (H, mm [in]) is the length of material that is consumed as a result of the forging action.

travel at I_1 (Q, mm [in]) is the dimension the movable platen (Material Y) travels during flashing current I_1.

travel at I_2 (R, mm [in]) is the dimension the movable platen (Material Y) travels during flashing current I_2.

upset current time (s) is the time during which upsetting current flow is taking place.

upset time (s) is the time during upsetting.

upset voltage (rms. V) is the total rms voltage that occurs across the workpieces during upsetting.

weld line is the plane of fusion of the welded parts.

weld time (s) is the time during which flashing and upset are taking place.

upset force (newton [lbf]) is the force exerted at the welding surfaces during upsetting.

upset current (rms. A) is the total rms current impulse or series of impulses that occur through the workpieces during upsetting.

6.4 Welding Variable Measurements

6.4.1 Dimensional Measurements. The dimensions below are usually obtained by scale measurement of the workpieces before and after welding.

(1) J = Material X loss

(2) K = Material Y loss

(3) L = Initial Extension – Material X

(4) M = Initial Extension – Material Y

(5) N = Final Extension – Material X

(6) P = Final Extension – Material Y

The following dimensions are usually obtained by scale measurement of such items on the welding machine.

(1) A = Initial Fixture Opening

(2) C = Final Fixture Opening

(3) D = Total Flash-loss

(4) E = Manual Flash-loss

(5) F = Automatic Flash-loss

(6) G = Preheat loss

(7) Q = Travel at Initial Current (I_1)

(8) R = Travel at Flashing Current (I_2)

The Total Upset (H) may be measured by subtracting the sum of the measurements of Total Flash-loss (D) and Preheat Loss (G) from the measurement of Material Loss (X).

6.4.2 Time Measurements. The following time intervals may be obtained by direct measurement with a stopwatch or can be obtained from an instrument such as an oscillograph, recording ammeter, recording wattmeter, or welding monitor.

(1) Preheat

(2) Manual Flashing

(3) Automatic Flashing

(4) Time at Flash Current I_1

(5) Time at Flash Current I_2

(6) Welding Cycle

(7) Quench or Cool

(8) Postheat

(9) Clamp Holding

6.4.3 Force Measurements. The Platen Force and Upset Force are of a transient nature and are influenced by the method of applying the forces, and by friction, inertia, and the opposing reaction of the material being upset. Consequently, it is difficult to obtain precise measurement of such forces without strain gauges or load cells.

The Clamping Force is usually calculated, the effect of friction being considered when making such calculations.

6.4.4 Current Measurements. Preheat Current, Flash Current, Upset Current, and Postheat Current can be measured with weld current monitoring equipment. Peak and RMS measurements may be used to characterize the electrical output driving the process during flashing, as well as during preheat, upset, and postheat stages when the parts are in intimate contact. However, to perform instantaneous measurements, such equipment must sample at a fast enough rate to effectively monitor the irregular current patterns occurring during flashing.

6.4.5 Voltage Measurements. Secondary Voltage can be measured with weld voltage monitoring equipment. Such equipment must sample at a fast enough rate to effectively monitor the irregular voltage patterns occurring during flashing.

6.4.6 Rates and Velocities of Flash-Loss and Upset. The Average Rate of Flash-Loss can be calculated from the Flash-Loss Time and Total Flash-Loss.

The Instantaneous Rate of Flash-Loss, Instantaneous Velocity of Upset, and Average Velocity of Upset can be measured by the use of any device which will satisfactorily record mechanical motion and time.

6.5 Classification of Steels for Flash Welding. The values of the upset forces required for various sections of various steels are related to the temperature gradient of the workpieces in the plastic zone and to the compressive strengths of the steels at these elevated temperatures. For consideration in applying the flash welding process to steels, such steels and their classes are grouped as follows:

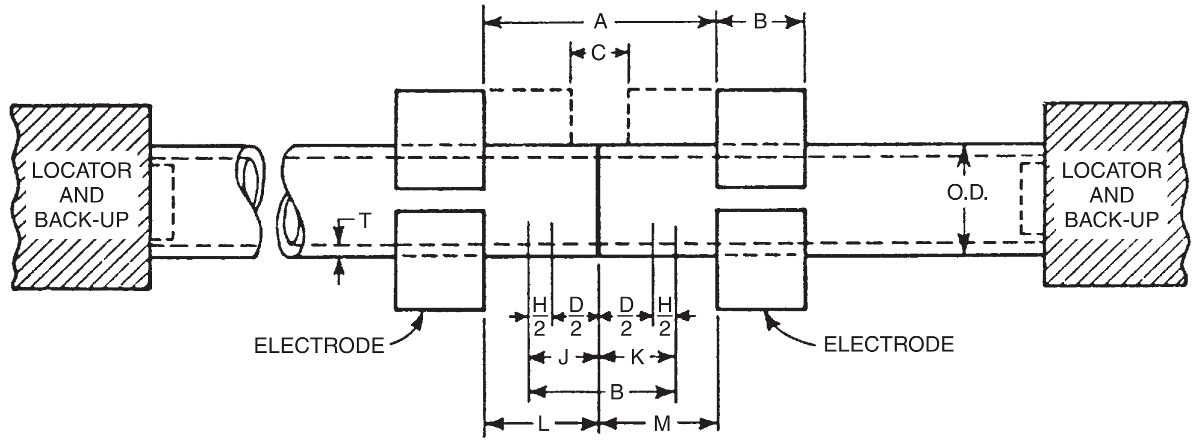
(1) Low-Forging Strength Steels. This class is typified by SAE 1020, 1112, 1315, and those steels commonly designated as high-strength low-alloy (HSLA) steels.

(2) Medium-Forging Strength Steels. This class is typified by SAE 1045, 1065, 1335, 3130, 3135, 4140, 8620, 8630, etc.

(3) High-Forging Strength Steels. This class is typified by SAE 4340 and 4640, stainless steel (12% chromium type), stainless steel (18–8 cutlery type), high speed steel, tool steel, etc.

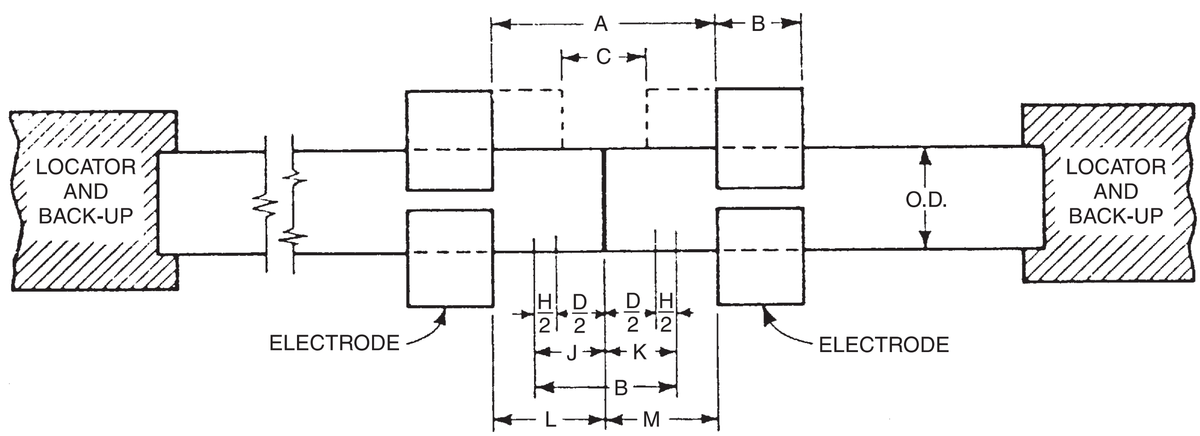
(4) Extra-High Forging Strength Steels. This class is typified by all steels exhibiting extra high compressive strengths at elevated temperatures, such as A–286 and 19–9DL.

6.6 Joint Preparation and Cleaning. The mating parts should be prepared in such a manner that the heat generated will be uniformly distributed over the section. Figures 32 and 33 show recommended end preparation for flash welding of flat sheet, tubing, solid round, hexagonal square, and rectangular bars.



A= INITIAL DIE OPENING
B = MATERIAL LOST
C = FINAL DIE OPENING
D = TOTAL FLASH-OFF
H = TOTAL UPSET
J = K = MATERIAL LOST PER PIECE
L = M = INITIAL EXTENSION PER PIECE
O.D. = OUTSIDE DIA. OF TUBING
S = MINIMUM NECESSARY LENGTH OF ELECTRODE CONTACT
T = TUBE WALL OR SHEET THICKNESS

Figure 32—Flash Welding of Tubing and Flat Sheets



A= INITIAL DIE OPENING
B = MATERIAL LOST
C = FINAL DIE OPENING
D = TOTAL FLASH-OFF
H = TOTAL UPSET
J = K = MATERIAL LOST PER PIECE
L = M = INITIAL EXTENSION PER PIECE
OD = OUTSIDE DIA. OF ROUNDS OR MINIMUM DIMENSION OF OTHER SECTIONS
S = MINIMUM NECESSARY LENGTH OF ELECTRODE CONTACT

Figure 33—Flash Welding of Solid Round, Hex, Square, and Rectangular Bars

Welding of tubing with a ratio of outside diameter-to-wall thickness greater than 30:1 is difficult and therefore not recommended. Additionally, welding of sheet with a width-to-thickness ratio of greater than 400:1 is difficult and therefore not recommended.

The surfaces of the parts contacting the dies and the surfaces to be welded should be clean and free from oxides, paint, grease, dirt, or foreign matter which would interfere with the passage of current through the workpiece. Chemical cleaning and grit blasting are preferred. Grit blasting should be followed by treatment to remove imbedded particles prior to welding.

6.7 Welding Schedules. The data shown in Tables 49 and 50 and Figures 32 and 33 are offered as a guide for developing flash welding schedules for various steels. Flash welding schedules for welding steel tubing and flat sheets having a thickness ranging from 0.25 to 25 mm [0.010 to 1.00 in] are given in Figure 32 and Table 49 and cover steels of low and medium forging strengths. Flash welding schedules for welding solid round, hexagonal, square, and rectangular steel bars having a diameter, for round bars, or minimum dimension, for other shaped bars, ranging from 1.3 to 50 mm [0.05–2 in] are given in Figure 33 and Table 50 and cover steels of low and medium forging strength. Refer to 6.3 for definitions of process variables.

These schedules show the necessary dimensions for setting up a flash welding machine to weld such sections and the total flash time based on welding without preheat. No data are given on the flash current, rates and velocities of flash and upset required due to the varying types of equipment used.

When setting up a schedule, the dimensional variables and flash time are selected from the tabulations. The machine volt age regulator is adjusted to give the lowest secondary voltage at which steady and consistent flashing can be maintained. The flash current resulting from such a voltage setting will then be at a satisfactory value. The secondary voltage to obtain this satisfactory flash current is dependent on the electrical characteristics of the welding machine being used.

The upset forces used for the schedules are dependent upon the class of steel as well as the section being welded. Experience indicates that the selection of equipment should be based on the following values of recommended platen force, and such values are based on the welding heat being attained solely by flashing using no preheat:

Low forging strength steels—70 MPa [10 ksi] of weld cross-sectional area.

Medium forging strength steels—100 MPa [15 ksi] of weld cross-sectional area.

High forging strength steels—170 MPa [25 ksi] of weld cross-sectional area.

Extra high forging strength steels—240 MPa [35 ksi] weld cross-sectional area.

It should be noted that the most common applications use no preheat or dual flash currents, but consist of flashing at a single current followed by upset.

6.8 Weld Discrepancies and Causes. Effective problem-solving in flash welding requires knowledge of weld discrepancies and their causes. Generally, the solution becomes obvious once the cause of the discrepancy is determined. The following are typical flash weld discrepancies and their possible causes:

(1) Cracks (usually in the upset metal)
- Metal not sufficiently plastic during upset
- Inadequate die opening
- Inadequate weld time
- Inadequate upset current

Cracks totally in the upset metal are considered acceptable because the upset metal is usually removed after welding.

(2) Weld Misalignment
- Clamp dies misaligned
- Clamp dies inadequately tightened
- Backstops misaligned
- Excessive welding machine deflection
- Clamp dies excessively worn
- Parts misaligned before welding

Table 49
Data for Flash Welding of Tubing and Flat Sheets

[See Figure 29 for Assembly of Parts]

T		A		B		C		D		M		J=K		L=M		Flash Time	O.D.		S With Locator		S Without Locator	
mm	[in]	mm	[in]	mm	[in]	mm	[in]	mm	[in]	mm	[in]	mm	[in]	m	[in]	sec.	mm	[in]	mm	[in]	mm	[in]
0.25	[0.010]	2.79	[0.110]	1.52	[0.060]	1.27	[0.050]	1.02	[0.040]	0.51	[0.020]	0.76	[0.030]	1.40	[0.055]	1.00	6.35	[0.250]	9.53	[0.375]	25.40	[1.000]
0.51	[0.020]	5.46	[0.215]	2.92	[0.115]	2.54	[0.100]	2.03	[0.080]	0.89	[0.035]	1.47	[0.058]	2.74	[0.108]	1.50	7.92	[0.312]	9.53	[0.375]	25.40	[1.000]
0.76	[0.030]	8.26	[0.325]	4.45	[0.175]	3.81	[0.150]	3.18	[0.125]	1.27	[0.050]	2.24	[0.088]	4.14	[0.163]	2.00	9.53	[0.375]	9.53	[0.375]	38.10	[1.500]
1.02	[0.040]	10.92	[0.430]	5.84	[0.230]	5.08	[0.200]	4.19	[0.165]	1.65	[0.065]	2.92	[0.115]	5.46	[0.215]	2.50	12.70	[0.500]	9.53	[0.375]	44.45	[1.750]
1.27	[0.050]	13.46	[0.530]	7.11	[0.280]	6.35	[0.250]	5.21	[0.205]	1.91	[0.075]	3.56	[0.140]	6.73	[0.265]	3.25	19.05	[0.750]	12.70	[0.500]	50.80	[2.000]
1.52	[0.060]	15.75	[0.620]	8.38	[0.330]	7.37	[0.290]	6.10	[0.240]	2.29	[0.090]	4.19	[0.165]	7.87	[0.310]	4.00	25.40	[1.000]	19.05	[0.750]	63.50	[2.500]
1.78	[0.070]	18.16	[0.715]	9.78	[0.385]	8.38	[0.330]	7.11	[0.280]	2.57	[0.101]	4.90	[0.193]	9.09	[0.358]	5.00	38.10	[1.500]	25.40	[1.000]	76.20	[3.000]
2.03	[0.080]	20.45	[0.805]	11.05	[0.435]	9.40	[0.370]	8.00	[0.315]	3.05	[0.120]	5.54	[0.218]	10.24	[0.403]	6.00	50.80	[2.000]	31.75	[1.250]	*[a]	*
2.29	[0.090]	22.48	[0.885]	12.07	[0.475]	10.41	[0.410]	8.76	[0.345]	3.30	[0.130]	6.05	[0.238]	11.25	[0.443]	7.00	63.50	[2.500]	44.45	[1.750]	*	*
2.54	[0.100]	24.64	[0.970]	13.21	[0.520]	10.92	[0.430]	9.53	[0.375]	3.68	[0.145]	6.60	[0.260]	12.32	[0.485]	8.00	76.20	[3.000]	50.80	[2.000]	*	*
2.79	[0.110]	26.92	[1.060]	14.48	[0.570]	12.45	[0.490]	10.41	[0.410]	4.06	[0.160]	7.24	[0.285]	13.46	[0.530]	9.75	88.90	[3.500]	57.15	[2.250]	*	*
3.05	[0.120]	28.96	[1.140]	15.49	[0.610]	13.46	[0.530]	11.18	[0.440]	4.32	[0.170]	7.75	[0.305]	14.48	[0.570]	10.25	101.60	[4.000]	63.50	[2.500]	*	*
3.30	[0.130]	31.12	[1.225]	16.51	[0.650]	14.61	[0.575]	11.94	[0.470]	4.57	[0.180]	8.26	[0.325]	15.57	[0.613]	11.00	114.30	[4.500]	69.85	[2.750]	*	*
3.56	[0.140]	33.53	[1.320]	17.78	[0.700]	15.75	[0.620]	12.95	[0.510]	4.83	[0.190]	8.89	[0.350]	16.76	[0.660]	12.75	127.00	[5.000]	69.85	[2.750]	*	*
3.81	[0.150]	35.31	[1.390]	18.54	[0.730]	16.76	[0.660]	13.46	[0.530]	5.08	[0.200]	9.27	[0.365]	17.65	[0.695]	13.50	139.70	[5.500]	76.20	[3.000]	*	*
4.06	[0.160]	37.34	[1.470]	19.56	[0.770]	17.78	[0.700]	14.22	[0.560]	5.33	[0.210]	9.78	[0.385]	18.67	[0.735]	14.00	152.40	[6.000]	82.55	[3.250]	*	*
4.32	[0.170]	39.12	[1.540]	20.32	[0.800]	18.80	[0.740]	14.73	[0.580]	5.59	[0.220]	10.16	[0.400]	19.56	[0.770]	15.75	165.10	[6.500]	88.90	[3.500]	*	*
4.57	[0.180]	41.15	[1.620]	21.34	[0.840]	19.81	[0.780]	15.49	[0.610]	5.84	[0.230]	10.67	[0.420]	20.57	[0.810]	16.50	177.80	[7.000]	95.25	[3.750]	*	*
4.83	[0.190]	42.93	[1.690]	22.10	[0.870]	20.83	[0.820]	16.00	[0.630]	6.10	[0.240]	11.05	[0.435]	21.46	[0.845]	17.25	190.50	[7.500]	101.60	[4.000]	*	*
5.08	[0.200]	44.70	[1.760]	22.86	[0.900]	21.84	[0.860]	16.51	[0.650]	6.35	[0.250]	11.43	[0.450]	22.35	[0.880]	18.00	203.20	[8.000]	107.95	[4.250]	*	*
6.35	[0.250]	51.05	[2.010]	25.65	[1.010]	25.40	[1.000]	18.54	[0.730]	7.11	[0.280]	12.83	[0.505]	25.53	[1.005]	24.00	215.90	[8.500]	114.30	[4.500]	*	*
7.62	[0.300]	57.02	[2.245]	28.45	[1.120]	28.58	[1.125]	20.57	[0.810]	7.87	[0.310]	14.22	[0.560]	28.52	[1.123]	30.00	228.60	[9.000]	120.65	[4.750]	*	*
8.89	[0.350]	62.48	[2.460]	30.73	[1.210]	31.75	[1.250]	22.35	[0.880]	8.38	[0.330]	15.37	[0.605]	31.24	[1.230]	36.00	241.30	[9.500]	127.00	[5.000]	*	*
10.16	[0.400]	67.06	[2.640]	32.77	[1.290]	34.29	[1.350]	23.62	[0.930]	9.14	[0.360]	16.38	[0.645]	33.53	[1.320]	42.00	254.00	[10.000]			*	*
11.43	[0.450]	70.61	[2.780]	34.29	[1.350]	36.32	[1.430]	24.64	[0.970]	9.65	[0.380]	17.15	[0.675]	35.31	[1.390]	48.00					*	*
12.70	[0.500]	73.91	[2.910]	35.81	[1.410]	38.10	[1.500]	25.91	[1.020]	9.91	[0.390]	17.91	[0.705]	36.96	[1.455]	54.00					*	*
13.97	[0.550]	77.22	[3.040]	37.21	[1.465]	40.01	[1.575]	26.24	[1.033]	10.41	[0.410]	18.62	[0.733]	38.61	[1.520]	60.00					*	*
15.24	[0.600]	79.63	[3.135]	38.23	[1.505]	41.40	[1.630]	27.56	[1.085]	10.67	[0.420]	19.13	[0.753]	39.83	[1.568]	66.00					*	*
16.51	[0.650]	82.42	[3.245]	39.50	[1.555]	42.93	[1.690]	28.58	[1.125]	10.92	[0.430]	19.76	[0.778]	41.22	[1.623]	73.00					*	*
17.78	[0.700]	85.34	[3.360]	40.89	[1.610]	44.45	[1.750]	29.46	[1.160]	11.43	[0.450]	20.45	[0.805]	42.67	[1.680]	80.00					*	*
20.32	[0.800]	89.54	[3.525]	42.55	[1.675]	46.99	[1.850]	30.73	[1.210]	11.81	[0.465]	21.29	[0.838]	44.78	[1.763]	92.00					*	*
22.86	[0.900]	92.96	[3.660]	43.94	[1.730]	49.02	[1.930]	31.75	[1.250]	12.19	[0.480]	21.97	[0.865]	46.48	[1.830]	104.00					*	*
25.40	[1.000]	96.52	[3.800]	45.72	[1.800]	50.80	[2.000]	33.02	[1.300]	12.70	[0.500]	22.86	[0.900]	48.26	[1.900]	116.00					*	*

[a] Not recommended for welding without use of locators.

Note: Data are based on welding without preheat, and for two pieces of same welding characteristics.

Table 50
Data for Falsh Welding of Solid Round, Hex, Square, and Rectangular Bars

See Figure 30 for Assembly of Parts

O.D.		A		B		C		D		M		J = K		L = M		Flash Time	O.D.		S With Locator		S Without Locator	
mm	[in]	mm	[in]	mm	[in]	mm	[in]	mm	[in]	mm	[in]	mm	[in]	mm	[in]	sec.	mm	[in]	mm	[in]	mm	[in]
1.27	[0.050]	2.54	[0.100]	1.27	[0.050]	1.27	[0.050]	1.02	[0.040]	0.25	[0.010]	0.64	[0.025]	1.27	[0.050]	1.00	6.35	[0.250]	9.53	[0.375]	25.40	[1.000]
2.54	[0.100]	4.62	[0.182]	2.08	[0.082]	2.54	[0.100]	1.57	[0.062]	0.51	[0.020]	1.04	[0.041]	2.31	[0.091]	1.50	7.92	[0.312]	9.53	[0.375]	25.40	[1.000]
3.81	[0.150]	6.86	[0.270]	3.05	[0.120]	3.81	[0.150]	2.29	[0.090]	0.76	[0.030]	1.52	[0.060]	3.43	[0.135]	2.00	9.53	[0.375]	9.53	[0.375]	38.10	[1.500]
5.08	[0.200]	8.89	[0.350]	3.81	[0.150]	5.08	[0.200]	2.79	[0.110]	1.02	[0.040]	1.91	[0.075]	4.45	[0.175]	2.50	12.70	[0.500]	9.53	[0.375]	44.45	[1.750]
6.35	[0.250]	10.92	[0.430]	4.57	[0.180]	6.35	[0.250]	3.30	[0.130]	1.27	[0.050]	2.29	[0.090]	5.46	[0.215]	3.25	19.05	[0.750]	12.70	[0.500]	50.80	[2.000]
7.62	[0.300]	12.95	[0.510]	5.33	[0.210]	7.62	[0.300]	3.81	[0.150]	1.52	[0.060]	2.67	[0.105]	6.48	[0.255]	4.00	25.40	[1.000]	19.05	[0.750]	63.50	[2.500]
8.89	[0.350]	15.24	[0.600]	6.35	[0.250]	8.89	[0.350]	4.57	[0.180]	1.78	[0.070]	3.18	[0.125]	7.62	[0.300]	5.00	38.10	[1.500]	25.40	[1.000]	76.20	[3.000]
10.16	[0.400]	17.40	[0.685]	7.24	[0.285]	10.16	[0.400]	5.21	[0.205]	2.03	[0.080]	3.63	[0.43]	8.71	[0.343]	6.00	50.80	[2.000]	31.75	[1.250]	*[a]	*
11.43	[0.450]	19.56	[0.770]	8.13	[0.320]	11.43	[0.450]	5.84	[0.230]	2.29	[0.090]	4.06	[0.160]	9.78	[0.385]	7.00	63.50	[2.500]	44.45	[1.750]	*	*
12.70	[0.500]	21.59	[0.850]	8.89	[0.350]	12.70	[0.500]	6.35	[0.250]	2.54	[0.100]	4.45	[0.175]	10.80	[0.425]	8.00	76.20	[3.000]	50.80	[2.000]	*	*
13.97	[0.550]	23.88	[0.940]	9.91	[0.390]	13.97	[0.550]	7.11	[0.280]	2.79	[0.110]	4.95	[0.195]	11.94	[0.470]	9.00	88.90	[3.500]	57.15	[2.250]	*	*
15.24	[0.600]	26.04	[1.025]	10.80	[0.425]	15.24	[0.600]	7.75	[0.305]	3.05	[0.120]	5.41	[0.213]	13.03	[0.513]	10.00	101.60	[4.000]	63.50	[2.500]	*	*
16.51	[0.650]	27.94	[1.100]	11.43	[0.450]	16.51	[0.650]	8.26	[0.325]	3.18	[0.125]	5.72	[0.225]	13.97	[0.550]	11.00	114.30	[4.500]	69.85	[2.750]	*	*
17.78	[0.700]	29.97	[1.180]	12.19	[0.480]	17.78	[0.700]	8.89	[0.350]	3.30	[0.130]	6.10	[0.240]	14.99	[0.590]	12.00	127.00	[5.000]	69.85	[2.750]	*	*
19.05	[0.750]	32.00	[1.260]	12.95	[0.510]	19.05	[0.750]	9.53	[0.375]	3.43	[0.135]	6.48	[0.255]	16.00	[0.630]	13.00	139.70	[5.500]	76.20	[3.000]	*	*
20.32	[0.800]	34.04	[1.340]	13.72	[0.540]	20.32	[0.800]	10.16	[0.400]	3.56	[0.140]	6.86	[0.270]	17.02	[0.670]	14.00	152.40	[6.000]	82.55	[3.250]	*	*
21.59	[0.850]	36.07	[1.420]	14.48	[0.570]	21.59	[0.850]	10.80	[0.425]	3.68	[0.145]	7.24	[0.285]	18.03	[0.710]	15.00	165.10	[6.500]	88.90	[3.500]	*	*
22.86	[0.900]	38.10	[1.500]	15.24	[0.600]	22.86	[0.900]	11.43	[0.450]	3.81	[0.150]	7.62	[0.300]	19.05	[0.750]	16.00	177.80	[7.000]	95.25	[3.750]	*	*
24.13	[0.950]	40.13	[1.580]	16.00	[0.630]	24.13	[0.950]	12.07	[0.475]	3.94	[0.155]	8.00	[0.315]	20.07	[0.790]	17.00	190.50	[7.500]	101.60	[4.000]	*	*
25.40	[1.000]	42.16	[1.660]	16.76	[0.660]	25.40	[1.000]	12.70	[0.500]	4.06	[0.160]	8.38	[0.330]	21.08	[0.830]	18.00	203.20	[8.000]	107.95	[4.250]	*	*
26.67	[1.050]	44.20	[1.740]	17.53	[0.690]	26.67	[1.050]	13.34	[0.525]	4.19	[0.165]	8.76	[0.345]	22.10	[0.870]	20.00	215.90	[8.500]	114.30	[4.500]	*	*
27.94	[1.100]	46.23	[1.820]	18.29	[0.720]	27.94	[1.100]	13.97	[0.550]	4.32	[0.170]	9.14	[0.360]	23.11	[0.910]	22.00	228.60	[9.000]	120.65	[4.750]	*	*
29.21	[1.150]	48.26	[1.900]	19.05	[0.750]	29.21	[1.150]	14.61	[0.575]	4.45	[0.175]	9.53	[0.375]	24.13	[0.950]	24.00	241.30	[9.500]	127.00	[5.000]	*	*
30.48	[1.200]	50.29	[1.980]	19.81	[0.780]	30.48	[1.200]	15.24	[0.600]	4.57	[0.180]	9.91	[0.390]	25.15	[0.990]	27.00	254.00	[10.000]			*	*
31.75	[1.250]	52.32	[2.060]	20.57	[0.810]	31.75	[1.250]	15.88	[0.625]	4.70	[0.185]	10.29	[0.405]	26.16	[1.030]	30.00					*	*
33.02	[1.300]	54.36	[2.140]	21.34	[0.840]	33.02	[1.300]	16.51	[0.650]	4.83	[0.190]	10.67	[0.420]	27.18	[1.070]	33.00					*	*
35.56	[1.400]	58.42	[2.300]	22.86	[0.900]	35.56	[1.400]	17.78	[0.700]	5.08	[0.200]	11.43	[0.450]	29.21	[1.150]	36.00					*	*
38.10	[1.500]	62.48	[2.460]	24.38	[0.960]	38.10	[1.500]	19.05	[0.750]	5.33	[0.210]	12.19	[0.480]	31.24	[1.230]	42.00					*	*
40.64	[1.600]	66.55	[2.620]	25.91	[1.020]	40.64	[1.600]	20.32	[0.80]	5.59	[0.220]	13.72	[0.540]	33.27	[1.310]	48.00					*	*
43.18	[1.700]	70.61	[2.780]	27.43	[1.080]	43.18	[1.700]	21.59	[0.850]	5.84	[0.230]	13.72	[0.540]	35.31	[1.390]	56.00					*	*
45.72	[1.800]	74.68	[2.940]	28.96	[1.140]	45.72	[1.800]	22.86	[0.900]	6.10	[0.240]	14.48	[0.570]	37.34	[1.470]	66.00					*	*
48.26	[1.900]	78.74	[3.100]	30.48	[1.200]	48.26	[1.900]	24.13	[0.950]	6.35	[0.250]	15.24	[0.600]	39.37	[1.550]	77.00					*	*
50.80	[2.000]	82.80	[3.260]	32.00	[1.260]	50.80	[2.000]	25.40	[1.000]	6.60	[0.260]	16.00	[0.630]	41.40	[1.630]	92.00					*	*

[a]Not recommended for welding without use of locators.

Note: Data are based on welding without preheat, and for two pieces of same welding characteristics.

(3) Flat Spots, Penetrators (Oxide Inclusions)
- Improper flashing acceleration just before upset
- Inadequate upset force or upset velocity
- Inadequate upset travel
- Inadequate flash travel
- Early cut-off of flash current
- Erratic flashing caused by excessive flashing voltage, excessive or inadequate flashing acceleration

(4) Die Burns (overheated areas in the workpiece at the location of the dies)
- Insufficient contact area between the die and the workpiece for the magnitude of current being passed
- Foreign material between the die and workpiece or surface contamination
- Insufficient clamping force

(5) Inadequate Weld Strength
- Improper upset travel
- Upset force too low
- Parts slipped in clamp dies due to inadequate clamp force or backup
- Improper flashing velocity or acceleration
- Flashing voltage too high
- Flash current phase shifting
- Current shut off too soon before upset
- Misaligned clamp dies
- Final die space too large (aluminum welding)
- Flash time too short
- Defects in metal being welded

6.9 Weld Quality and Mechanical Property Tests

6.9.1 Destructive Weld Quality Tests

6.9.1.1 Metallographic Test. Metallographic examination should be used to evaluate flash welded joints for soundness and microstructure during welding procedure development. It may also be used as a process control tool during production welding. One or more sections from a sample welded joint should be taken and polished, etched, and optically examined for acceptability.

6.9.2 Nondestructive Weld Quality Tests. Fluorescent dye penetrant, radiographic, and ultrasonic inspections may be performed to determine the soundness of flash welded joints. Additionally, magnetic particle inspection may be performed on flash welded joints of magnetic metals. These inspections should be performed after removal of the weld flash.

Since normally specified nondestructive inspections may not adequately reveal the weld quality, proof load testing should be performed on flash welded joints for critical applications. A common proof test for flash welded rings is to size the ring to provide a permanent expansion of not less than 1 percent across a 50 mm [2 in] gauge length centered on the weld. The test is performed after removal of the weld flash. For heat treated rings, the test is performed after cooling to room temperature from heat treatment. The test is performed in such a way that the stress is uniformly distributed throughout the ring. However, this test does not detect all defective welds. A more stringent proof test should be used where it is justified by the application.

6.9.3 Mechanical Property Tests. Standard mechanical property tests for evaluating the base metals can be used for evaluating the mechanical properties of flash welded joints. The test specimen gage section should be centered on the weld. For notched specimens, the notch should be centered on the weld. Weld joints which are heat treated before service should be tested in the heat-treated condition.

Mechanical property tests, such as tensile and bend-tests, may be performed to determine the deterioration in performance of the welding machine with time. These tests should be conducted on welded samples before, at regular intervals during, and after a production run. The test specimens should have the same cross-sectional area in the weld area as the production parts to be welded, and be of the same metal and heat treatment condition. The specimens should be tested in full section whenever practical. Reduced section test specimens may be removed from the welded joint if the full section is too large to test. The reduced section specimen should contain at least 50 percent of the original weld interface area. The weld flash should be removed from both types of specimens to eliminate unsound metal from the weld.

7. Upset Welding

7.1 Introduction. Upset welding (UW) is a resistance welding process producing coalescence over the entire area of faying surfaces or progressively along a butt joint by the heat obtained from the resistance to the flow of welding current through the area where those surfaces are in contact. Pressure is used to complete the weld. The two pieces of metal are similar in cross-section. Pressure is applied before the current is started and maintained throughout the joining process.

Upset welding is similar to flash welding. The main difference between the two processes is there is no flashing at the abutting surfaces in upset welding.

7.2 Equipment. The welding equipment must be capable of bringing the faying surfaces into intimate contact, controlling the secondary voltage and current, and allowing the welded joint to achieve coalescence and cool before removing the welding force. Equipment is available for welding:

(1) Two sections with the same cross-sectional area and shape end-to-end.

(2) Longitudinal seams progressively along the butt joint.

7.3 Welding Variables. Because of the similarity between the two processes, upset welding has the same basic process variables as flash welding, except the flashing variables. The variable measurements can be the same in both processes. The flash welding variables and their measurements are described in 6.3 and 6.4, respectively.

7.4 Joint Preparation and Cleaning. Machined faying surfaces should be used because of the need for intimate contact between them during welding. For thin sheets or plates, the faying surfaces may be obtained by shearing. They should be parallel when the workpieces are loaded in the welding machine.

Prior to welding, the faying surfaces and those of the workpiece contacting the dies should be cleaned to remove oxides, paint, grease, dirt, or foreign matter that can contaminate the weld or impede the passage of current through the work piece. Cleaning operations that may leave a contaminant on the workpiece (e.g., grit blasting) should be followed by an operation to remove the contaminant.

7.5 Welding Parameters. The data shown in 6.7 for flash welding of various steels and shapes, except those related to producing flash, can be used as a guide to develop upset welding schedules for the same steels and shapes because of the similarity between the two processes.

7.6 Weld Quality and Mechanical Property Tests

7.6.1 Destructive Weld-Quality Tests

7.6.1.1 Metallographic Test. As in flash welding, metallographic examination should be used to evaluate upset welded joints for soundness and microstructure during the welding procedure development. It may also be used as a process control tool during production welding. One or more sections should be taken from a given sample welded joint, polished, etched, and optically examined for acceptability.

7.6.1.2 Bend Test. A bend test may be used to evaluate the quality of upset welds. A typical example of a bend test uses a butt joint in a wire weld. The sample is bent back and forth until it breaks. The weld quality is considered acceptable if the fracture occurs outside the weld.

7.6.3 Nondestructive Weld Quality Tests. Fluorescent liquid penetrant, radiographic, and ultrasonic inspections may be performed to determine the soundness of upset welded joints. Additionally, magnetic particle inspection may be performed on welded joints of magnetic metals.

7.6.4 Mechanical Property Tests. Standard mechanical property tests for evaluating the base metals can be used to evaluate the mechanical properties of upset welded joints. The test specimen gauge section should be centered on the weld. For notched specimens, the notch should be centered on the weld. Welded joints which are heat treated before service should be tested in the heat-treated condition.

Mechanical property tests, such as tensile and bend-tests, may be performed to determine the deterioration in performance of the welding machine with time. These tests should be conducted on welded samples before, at regular intervals during, and after a production run. The welded sample should have the identical joint geometry as the production parts to be welded, and be of the same metal and heat treatment condition. The test specimen taken from the sample should contain the full weld cross section whenever practical. Reduced section test specimens may be removed from the welded joint, if the full section is too large to test. When smaller size test specimens are used, they should contain at least 50 percent of the original weld cross section.

8. Weld Bonding

8.1 Introduction. Weld bonding is a resistance spot-welding process variation in which the spot-weld strength is augmented by adhesive at the faying surface. It is the same as adhesive bonding except that resistance welds are used to hold the components together during the cure cycle instead of using autoclaves and tooling fixtures. A paste or film adhesive is placed between the surfaces to be joined. Resistance welds are then made using conventional equipment. If a paste adhesive is used, the adhesive should be kept from the faying surfaces beneath the electrodes during the build-up of electrode force prior to the application of weld current. If a film adhesive is used, there should be no adhesive in the areas to be resistance welded because it impedes the flow of current between the faying surfaces. Once the resistance welding operation has been completed, the assembly is then allowed to cure in an oven or at ambient temperature, as recommended by the manufacturer.

Weld bonding has been employed for many years in the aerospace industry for structural applications. In high volume industries such as the automotive industry, the same techniques have been used for nonstructural applications involving weld-through sealers. However, there is a growing interest in these industries in the use of weld bonding in place of resistance welding for structural applications involving both coated steels and aluminum alloys. The attractive features of using weld bonding instead of exclusive resistance welding are higher static shear strength, joint sealing, reduced vibration, improved stress distribution, and fatigue strength.

Care should be employed to understand different adhesives have different properties; characteristics such as toxicity and fume hazard, especially in regard to performance under varying humidity and temperature conditions, curing times, strength of material, thixotropy (changing properties of the adhesives as they flow under heat and pressure), viscosity, pyrolyse (cracking under heat and pressure), and regular electrode factors. Properties of the adhesive may also be altered during the welding process as a result of interactions with melted coatings or the redistribution of adhesive constituents.

8.2 Aluminum Alloys. Weld bonding of aluminum alloys has been conducted in the aerospace industry for many years, and consequently, most of the data available has been generated in this area.

8.2.1 Surface Condition. The surface condition of aluminum alloys has by far the greatest effect on static shear strength and durability of weld-bonded joints. The two main requirements of static strength and durability are both dependent on the character of the surface oxide and are affected by surface contaminants. The normal mode of deterioration of an adhesive bond in a hostile environment is the introduction of moisture between the bonding surfaces and the adhesive. The nature and porosity of the surface oxide has an effect on this mechanism. For resistance welding, the surface should be clean and have a low and consistent resistance. This can be achieved by chemical or mechanical cleaning to remove the oxide and surface contaminants as described in 4.3. However, for weld-bonded joints subject to exposure to harsh environments, such as in military aircraft, chemically or mechanically cleaned faying surfaces would not have adequate durability. For such applications, the surfaces should be preweld anodized. A low-voltage anodizing treatment has been developed, in conjunction with an adhesive containing strontium chromate, to obtain the required bondline durability for aerospace applications. This low-voltage anodizing procedure is shown in Table 51. For joints not subject to exposure to harsh environments, chemically or mechanically cleaned faying surfaces may prove to be satisfactory.

8.2.2 Weld Parameters. Anodized surfaces require different welding parameters compared with chemically and mechanically cleaned surfaces. If a short duration, high current pulse, as is used for chemically or mechanically cleaned surfaces, is used on anodized surfaces, expulsion will take place. To avoid expulsion, a long up-slope current, short forge delay time, and high electrode force should be used. Table 52 shows the difference in welding parameters for spot welding and weld bonding due to the surface condition and the addition of a paste adhesive to the faying surfaces.

Anodized surfaces may require a change in the spot-weld spacing and the electrode maintenance requirements. The high contact resistance at the anodized faying surface promotes a high shunting current through previously formed welds. Therefore, the weld spacing should be at least 1.5 times greater than that for conventional spot welding on nonanodized surfaces for the same applied weld schedule. With the anodized surface in contact with the electrode, the electrode pick-up will be greater than that of conventional spot welding for the same applied weld schedule. Electrode cleaning will be

Table 51
Weld-Bonding Surface Preparation for Aluminum Alloys by Low-Voltage Anodizing

Operation	Material[a]	Process
Vapor Degrease	111, Trichloroethylene	Vapor 60 sec. Condensed fluid 60 sec. Cool, Repeat until condensation on part ceases
Alkaline Clean	Turco 4215S; 45–60 gm/L	12–15 minutes, 63° –74°C [145° –165°F]
Spray Rinse	Cold deionized water	5–7 minutes
Deoxidize	Amchem No. 7: Nitric acid (Modified) Nitric acid: 11–14% by volume 42 (70% HNO_3) Amchem No. 7: 22–25 gm/L Alodine No. 45: 3–3.2 ml/L Alodine 1200E: 3.5–3.6 ml/L	7–8 min Room temperature Agitated and filtered tank Metal removal: 0.050–0.080 gm on 7.5 cm × 7.5 cm on 7075-T6 bare etched for 20 min with no agitation
Spray Rinse	Cold tapwater	5 min
Spray Rinse	Cold deionized water	5–7 min
Anodize	Phosphoric/Sodium dichromate solution. Phosphoric acid: 9–12 ml/L (85% H_3PO_4) Sodium dichromate: 9–12 gm/liter Deionized water: balance	20–22 min. Room temperature Air agitated and filtered tank 1.4–1.6 Volt for bare alloys 0.9–1.1 Volt d–c for clad alloys
Spray Rinse	Cold deionized water	5–7 min
Oven Dry	Circulating hot air	65° ± 5°C [150° ± 10°F]

[a] These materials may be hazardous. Refer to the Manufacturer's Safety Data Sheet.

required more frequently. Typical welding parameters for 1.6 mm [0.063 in] thick anodized 7075-T6 sheets are shown in Table 53, and commonly used metric conversions are shown in Table 54. Welding parameters for thinner or thicker aluminum alloy sheets can be obtained by adjusting the welding heat. Neither the weld time nor the forge delay time should be varied. However, the electrode force and forge force should be changed when a joint of different thickness is welded. The radii of electrodes should also be varied according to the sheet thickness.

8.2.3 Mechanical Properties. A weld-bonded joint has much higher static and dynamic failure loading than a resistance welded joint due to the adhesive-bonded area. Figure 34 shows a comparison of the failure load between the uncured joint (spot weld), and the cured joint as a function of the welding current. An increase of the weld current increases the nugget size, which increases the weld strength. The failure load of the cured weld-bonded joint is higher than that of the spot weld and is not affected by the weld current. This is due to the fact that the failure load of the adhesively bonded joint is much stronger than that of the spot weld, because of the larger area of bonding, and that the failure load represents the strength of the adhesive-bonded joint rather than the spot weld. As shown in Figure 35, the fatigue strength of the weld-bonded joint is almost as good as the adhesive-bonded joint, although the former has stress risers at the spot-weld periphery.

8.3 Other Metals. The weld-bonding process can also be used for other metals, such as steels and titanium alloys. The advantage of increased joint strength from weld-bonding compared with resistance welding alone will be reduced as the strength of the substrate increases. The objectives of using weld bonding for steels and titanium alloys are different from that for aluminum alloys. Weld bonding is not used for increasing joint strength but for sealing out moisture from the faying surface, improving acoustic damping ability, and for reducing vibration (e.g., in hoods, doors, and deck lids in automobiles). The surface treatment for conventional adhesive bonding of steels and titanium alloys can be used for weld bonding of these materials. Satisfactory results may be obtained using conventional resistance welding preweld treatments;

Table 52
Comparison between Resistance Spot-Welding and Weld-Bonding of Aluminum Alloys[a,b,c]

Surface Condition	Spot Welding	Weld Bonding
	Existing Oxide Removed	Existing Oxide Removed, Oxide Deposited by Low-Voltage Anodizing
	Low Contact Resistance <100 μΩ	High Contact Resistance 800 μΩ
Net Electrode Force	5.8 kN [1300 lb] Weld, 13.3 kN [3000 lb] Forge	8.9 kN [2000 lb] Weld, 17.8 kN [4000 lb] Forge
Welding Current	54 000 Amps	50 000 Amps
Welding Time	7 Cycles	25 Cycles
Joint Strength	3.6–4.4 kN [800–1000 lb]	22.2 kN [5000 lb]
Spot Spacing	25–38 mm [1–1.5 in]	50–100 mm [2–4 in]

[a] Alloys: 2024, 7075, 7475, 221.
[b] Sheet thickness: 1.6 mm (0.063 in).
[c] Adhesive: modified epoxy.

Table 53
Typical Spot-Welding Parameters[a] for 1.6 mm (0.063 in) Thick 7075-T6 Aluminum Treated with a Low-Voltage Anodizing Process

Electrode material	RWMA Class 1
Electrode (shank) diameter	15.88 mm [0.625 in]
Electrode tip radius	150 mm [6.0] in
Net electrode force	8.9 kN [2000 lb]
Forge force	17.8 kN [4000 lb]
Forge delay time	3 cycles
Upslope	10 cycles from 15% to 40% heat 5 cycles from 40% to 56% heat (48 kA)[b]
Welding time	2 cycles (at the peak)
Welding heat	56% 48kA)
Downslope	3 cycles from 56% to 32% heat[b] 5 cycles from 32% to 20% heat
Hold time	200 cycles

[a] A welding control capable of varying heat at each cycle is preferred.
[b] Not a straight line.

Table 54
Commonly Used Metric Conversions Inch-Millimeter Conversion

To convert inches to millimeters, multiply the inch value by 25.4

Inch and Millimeter Decimal Equivalents of Fractions of an Inch

Inch			Inch		
Fraction	Decimal	Millimeter	Fraction	Decimal	Millimeter
1/64	0.015	0.396	33/64	0.515	13.096
1/32	0.031	0.793	17/32	0.531	13.493
3/64	0.046	1.190	35/64	0.546	13.890
1/16	0.062	1.587	9/16	0.562	14.287
5/64	0.078	1.984	37/64	0.578	14.684
3/32	0.093	2.381	19/32	0.593	15.081
7/64	0.109	2.778	39/64	0.609	15.478
1/8	0.125	3.175	5/8	0.625	15.875
9/64	0.140	3.571	41/64	0.640	16.271
5/32	0.156	3.968	21/32	0.656	16.668
11/64	0.171	4.365	43/64	0.671	17.065
3/16	0.187	4.762	11/16	0.687	17.462
13/64	0.203	5.159	45/64	0.703	17.859
7/32	0.218	5.556	23/32	0.718	18.256
15/64	0.234	5.953	47/64	0.734	18.653
1/4	0.250	6.350	3/4	0.750	19.050
17/64	0.265	6.746	49/64	0.765	19.446
9/32	0.281	7.143	25/32	0.781	19.843
19/64	0.296	7.540	51/64	0.796	20.240
5/16	0.312	7.937	13/16	0.812	20.637
21/64	0.328	8.334	53/64	0.828	21.034
11/32	0.343	8.731	27/32	0.843	21.431
23/64	0.359	9.128	55/64	0.859	21.828
3/8	0.375	9.525	7/8	0.875	22.225
25/64	0.390	9.921	57/64	0.890	22.621
13/32	0.406	10.318	29/32	0.906	23.018
27/64	0.421	10.715	59/64	0.921	23.415
7/16	0.437	11.112	15/16	0.937	23.812
29/64	0.453	11.509	61/64	0.953	24.209
15/32	0.468	11.906	31/32	0.968	24.606
31/64	0.484	12.303	63/64	0.984	25.003
1/2	0.500	12.700	1	1.00	25.400

however, the environment can affect the long-term durability of the joint. In either case, conventional welding schedules developed without adhesives will usually yield acceptable weld quality. For some adhesives, an increase in electrode force or a change in weld time, or both, may be necessary.

8.4 Weld-Bonding Quality and Mechanical Property Tests. Various quality and mechanical property tests can be performed on weld-bonded joints. In process monitoring, radiographic and ultrasonic inspections can be used to determine the quality of the joint areas. The tests described in 4.9 for spot welds are applicable to spot welds in weld-bonded joints in the uncured condition. Fatigue testing of weld-bonded joints in aluminum alloys can be performed using the test specimen shown in Figure 36.

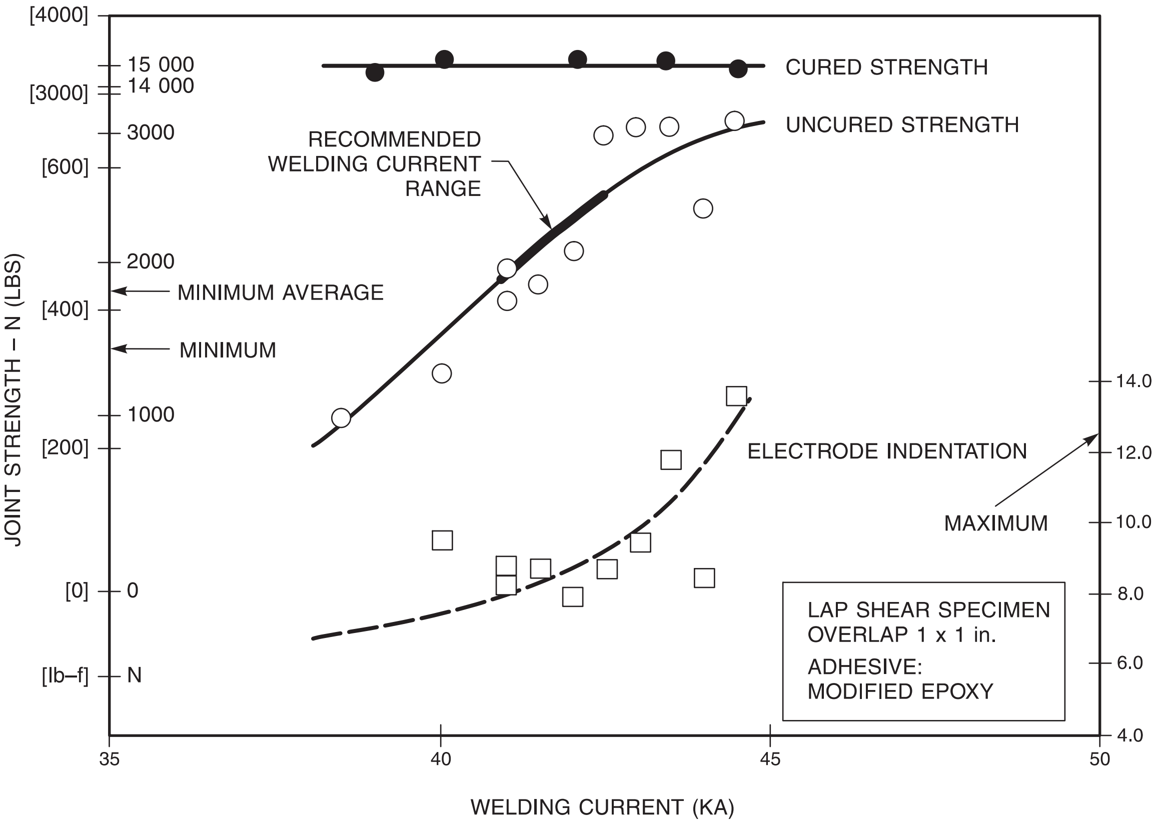


Figure 34—Comparison of Tensile-Shear Strengths of Uncured and Cured (Single Spot) Weld-Bonded Joints of 7075-T6 Aluminum Alloy

9. Equipment Monitoring and Maintenance

Production of consistently acceptable, high quality resistance welds requires an effective machine maintenance program. The following has been adapted from a listing of recommended periodic inspection and service for resistance welding equipment in the RWMA *Resistance Welding Manual*. Additional information can be found in the equipment manufacturer's manual.

DAILY:

At the start of each work shift, the following items should be done:

(1) Turn on the air supply.

(2) Turn on the water supply.

(3) Check for water circulation.

(4) Check the air pressure setting.

(5) Lubricate the required points daily.

(6) Turn on power supplies.

(7) Check the settings on the weld control.

(8) Dry cycle the equipment a few times to make sure everything is functioning properly.

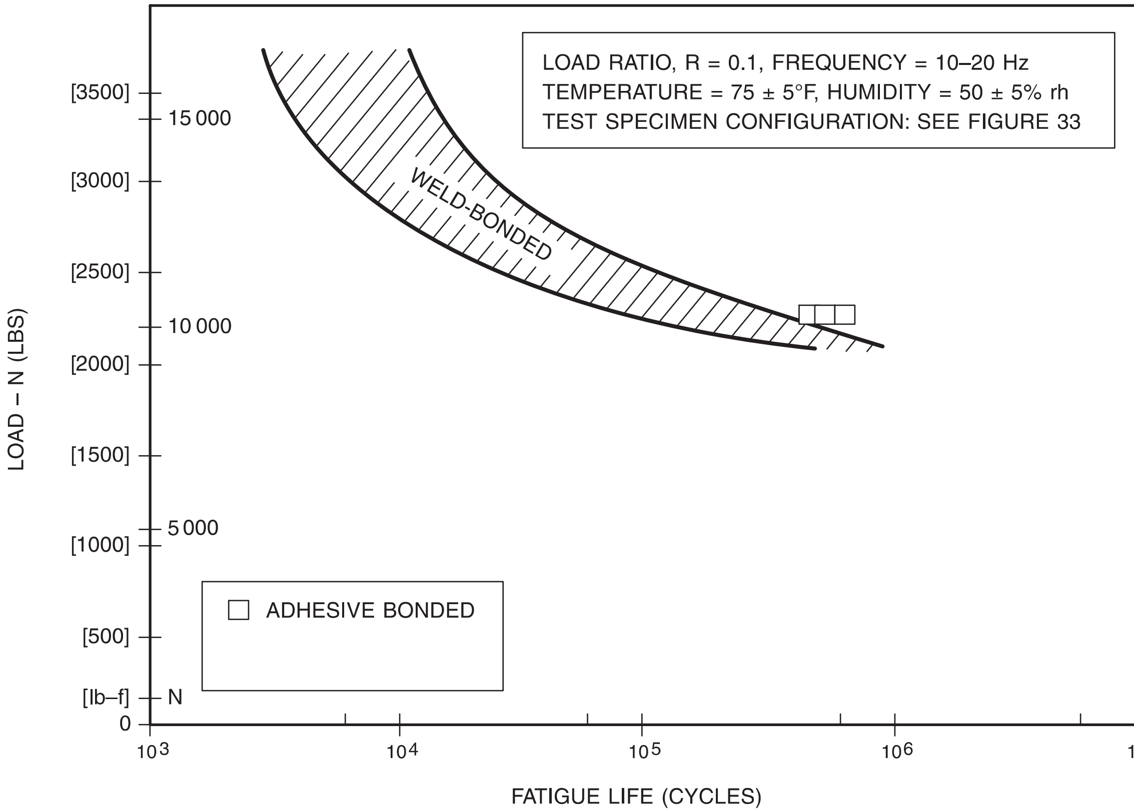


Figure 35—Comparison of Fatigue Test Results of Weld-Bonded and Adhesive-Bonded Joints of 7075-T6 Aluminum Alloy

(9) Check all variables after a few welds, to see that the water, air, machine settings, and contactors are working properly.

(10) Check the welds for desired quality.

At the end of each shift, the following items should be done:

(1) Turn off the electrical supply.

(2) Turn off the air supply.

(3) After 10–15 min, turn off the water supply to the weld contactor.

(4) Wipe all surfaces clean of dirt, dust, grease, oil, and water.
- Pay particular attention to cleaning clamp surfaces.
- Clean the machine and work area.
- Dust lenses of any light fixtures, windows and doors, and transparent covers.

Other system checks are:

DAILY:

(1) Cooling System
- Check for water leaks and make necessary repairs.

(2) Electrical system and control
- Check for chattering relays or switches and make necessary repairs.

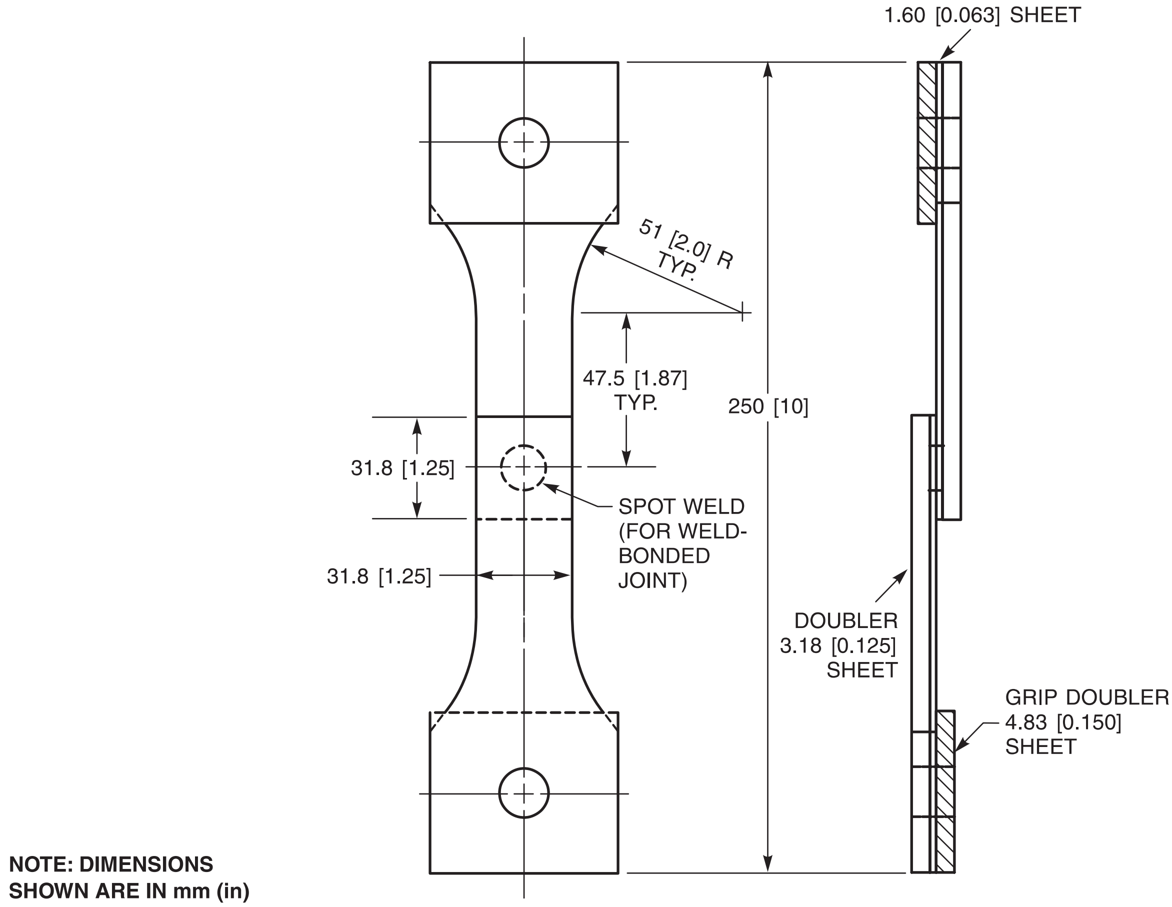


Figure 36—Fatigue Test Specimen of Weld-Bonded and Adhesive-Bonded Joints

- Check timers and controls for proper dial settings according to the schedule chart.
- Check for disabled interlocks or safety devices.
- Listen for noises indicating loose secondary connectors or broken leads.
- Check for burned out bulbs and indicator lights, enclosure lights, and other illumination features.

(3) Air System
- Check for air leaks and repair.
- Check line pressure and welding pressure.
- Drain air-line filters.
- Check lubricator oil levels.
- Feel solenoid valves for overheating—listen for hum indicating improper seating of spool.

(4) Electrodes and Fixtures
- Check lubrication of seam-welding heads.
- Check for discoloration on water-cooled components indicating improper cooling.
- Check for pitted, worn, or dirty electrodes.
- Check for grooves or markings of fixture.
- Check electrode and fixture alignment.

(5) Mechanical Equipment
- Lubricate as prescribed.
- If an automatic or centralized lubricating system is used, check for insufficient or excessive amounts of lubricants and adjust as necessary.

- Replace access covers.
- Check for broken or loose components.

(6) Hydraulic System
- Wipe top of reservoir.
- Check for fluid leaks and make necessary repairs.
- Check the reservoir for overheating.
- Listen for unusual pump noises.
- Check pressure gauge settings.

WEEKLY:

- Remove all oil spots from floor in walk areas.
- Wash down floor in area of machine.
- Check air and water leads.

If equipment has a standby mode, switch to "standby" (no weld) and check machine operation. After determining satisfactory operation, return to "run" position. In addition, the following items should be done:

(1) Electrical System and Control
- Check relays for evidence of wear or looseness.
  (Never attempt to adjust relays as routine maintenance. Contact tension and quick operation are preset and should not require adjustment.)
- Check programmable controls for unauthorized changes in the program and correct before placing back into operation.
- Sequence machine through full manual sequence.
- Clean nameplates.

(2) Electrode and Fixtures
- Make a thorough inspection of electrodes and electrode holders.
- Clean electrode or fixture holders and clamps.
- Check for misalignment and realign if necessary.

(3) Hydraulic System
- Check cylinder rod locking nuts.
- Remove sample of oil from reservoir and test for deterioration or contamination. (Testing interval will depend on fluid used and its age. Check fluid supplier for recommendation.)
- Check fluid filters.

(4) Air System
- Check cylinder rod locking nuts.
- Check cylinder mounting and tighten if necessary.
- Check and clean out water traps and filters.

MONTHLY:

(1) General
- Make a special check for air leaks through valve seats and cylinder packing. Inspect all hoses for unusual wear and replace if required.

In addition, all relay and switch contacts should be inspected for cleanliness and pitting. The contact surfaces should be cleaned as required. A thorough visual inspection of the entire machine, its controls, and all accessories should be made for loose or missing parts. Replace or tighten as required.

(2) Cooling System
- Reverse flush entire system to remove any accumulation of foreign matter. Verify volume of water flow.
- Remove and clean strainers and filters.
- Replace worn or cracked hoses.
- Tighten hose clamps.
- Check water temperature and pressure.
- Check water shutoff solenoids for proper operation.

(3) Electrical System and Control
- Check control timing and power factor with oscilloscope or other appropriate equipment. If this equipment is not available, contact your welding machine manufacturer and request assistance.
- Check ground connections for good contact.
- Tighten all terminal screw connections and visually examine soldered connections.
- Check line voltage with and without machine load. Variation should not exceed ± 10 percent.
- Remove vent filters (if any) and replace or clean.
- Check insulation for cracks and dirt accumulation. Replace if necessary.
- Clean all electrical components, sockets, cables, printed circuit boards, and like equipment.
- Check transformer leads for cracks or splits.
- Check primary grounds.

(4) Air System
- Remove air filter and clean.
- Check for loose cylinder bolts or hold-down plates.
- Check shock blocks for secure weldments.
- Check cylinders for air leaks and rods for score marks.
- Check for excessive sluggishness or sticking of cylinder. Caution must be used when checking pneumatic cylinders, since some spot or press welding heads will descend if air pressure is removed.
- Check air gauge for excessive pressure drops during operation of welding electrode holders.
- Check all speed control settings. Adjust and lock.

QUARTERLY:

(1) General
- Use master level and check machine. Re-level if necessary.

(2) Cooling System
- Check system thoroughly and replace components which show wear or corrosion.

(3) Electrical System
- Polish all secondary contact surfaces to remove corrosion. Use an approved cleaning solvent. Some solvents are toxic and breathing the fumes can cause dizziness. Other solvents are flammable and require good ventilation; therefore, proper precautions should be taken. In the case of excessive corrosion, a fine abrasive should be used.
- Tighten all connections for good contact.
- Check protective and overload devices.

(4) Air System
- Check air gauges and regulators with pressure indicator. Replace damaged regulators and gauges and those that are sluggish or need calibration.
- Check regulator diaphragms carefully.
- Replace worn or cracked air hoses with new hoses. Be sure connections are tight. High volume, high pressure air hoses should receive special consideration. Poor hose connections may blow off and cause injury.
- Clean or replace air-line mufflers, lubricators, and filters.

(5) Hydraulic System
- If recommended by oil supplier, replace oil in reservoir with new oil.
- Change or clean oil filters.

ANNUALLY:

(1) General
- A minor overhaul of the machine should be made annually, probably during inventory shutdown or model change-over. Remove all grease and rust from the machine and apply a coat of machinery paint.
- Check for excessive wear of trunnions, bearings, brushes, etc. and replace worn or damaged parts.

(2) Electrical System and Control
- Check calibration of timing and adjust if necessary.

(3) Air System
- Replace air hoses where required. When replacing air hoses or piping, oil the inside with a small amount of light-weight oil.

(4) Hydraulic System
- Change oil if recommended or necessary.

(5) Removing Equipment from Service

If a piece of resistance welding equipment is being removed from service for a period of time, the following should be done to prevent unnecessary damage during the idle time:

- Drain and blow out water from all cooling lines, especially:
  - Weld controls, including either ignitron tubes or SCR packages
  - Welding transformers
  - Electrode holders
- Drain hydraulic fluid, if used.
- Protect all nonpainted surfaces from rust and corrosion.
- Protect the inside and outside of cylinders from rust.
- Cover the equipment to prevent dirt accumulation.
- Store equipment in a dry location.

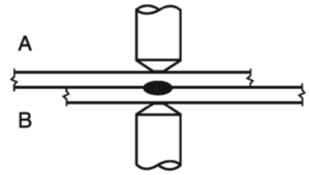
RESISTANCE WELDING DATA SHEET

EQUIPMENT IDENTIFICATION

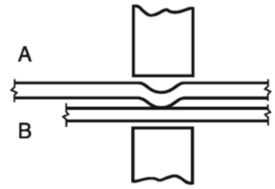
TYPE ____________________ SERIAL __________

TRANSFORMER NO. _______ RATING __________

CONTROL ________________________________



SPOT



PROJECTION

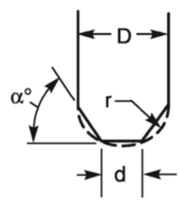
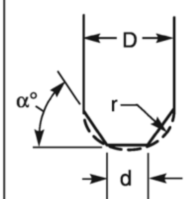
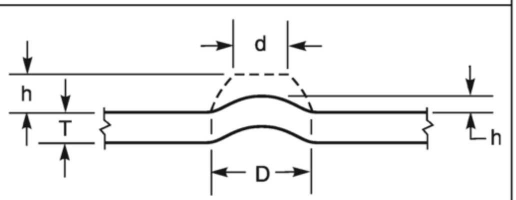
		SIDE A	SIDE B		
MATERIAL	Thickness			Weld Current	
	Approx. Analysis (type)			S. C. Current	
				Tap and/or Phase Setting	
				Throat Opening	
	Surface Cond.			Throat Spacing	
	Ultimate Strength			Synchronous or non-synchronous timing	
	Yield Strength				
	Elongation %			Heat Time	
	Red. in Area %			Squeeze Time	
	Hardness			Cool Time	
	Material			Hold Time	
ELECTRODE	Shape			No. of Pulsations	
				Electrode Force	
				Squeeze Force	
				Forging Force	
				Tension Shear Test	
				Tension Test	
SPOT	Diameter			TORSIONAL	Yield Point
	Overlap or Flange				Ultimate
	Spacing				Mod. of Rupt.
PROJECTION	Size Contour 				Degree Twist at Ult.
				Indentation	
				Nugget Size	
				Other Tests:	
	Number				
	Location				
	Remarks:			Photos	

Figure 37—Form for Resistance Welding Data Sheet for Spot and Projection Welding

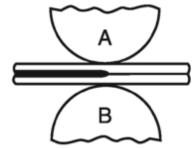
RESISTANCE WELDING DATA SHEET

EQUIPMENT IDENTIFICATION

TYPE ____________________ SERIAL __________

TRANSFORMER NO. _______ RATING __________

CONTROL ___________________________________



SEAM

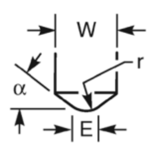
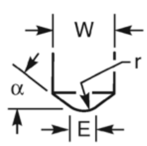
		SIDE A	SIDE B		
MATERIAL	Thickness			Weld Current	
	Approx. Analysis (type)			S. C. Current	
				Tap and/or Phase Setting	
				Throat Opening	
	Surface Cond.			Throat Spacing	
	Ultimate Strength			Synchronous or Non-synchronous Timing	
	Yield Strength				
	Elongation %			Heat Time	
	Red. in Area %			Cool Time	
	Hardness			Electrode Force	
ELECTRODE	Material			Tension Shear Test	
	Shape			Tension Test	
				TORSIONAL	Yield Point
					Ultimate
					Mod. of Rupt.
					Degree Twist at Ult.
SEAM	Roll Speed mm per min. (in per min)			Indentation	
	Spots per mm (in)			Other Tests:	
	Width of Weld				
MASH	Overlap or Filler				
	Length of Weld				
	Remarks:			Photos	

Figure 38—Form for Resistance Welding Data Sheet for Seam Welding

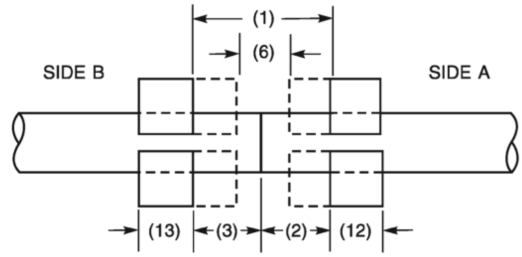
RESISTANCE WELDING DATA SHEET

MACHINE DESCRIPTION ______________________

____

MFGR. ____

kVA ________________ SERIAL ______________



MATERIAL DATA	SIDE A	SIDE B	MACHINE DATA (in)	
Approx. Analysis (type)			1. Initial Die Opening	
			2. Material Extension A	
Thickness			3. Material Extension B	
Width			4. Total Flash Off	
Diameter			5. Total Upset	
Area			6. Final Die Opening	
Surface Cond.			7. Total Material Loss	
Ult. Strength			ELECTRODE DATA	
Yield Strength			8. Electrode Material A	
Elongation %			9. Electrode Material B	
Red. in Area %			10. Clamping Force A kN (lb)	
Hardness			11. Clamping Force B kN (lb)	
Shape			12. Contact Length A mm (in)	
			13. Contact Length B mm (in)	

	PREHEAT	INITIAL FLASHING	FINAL FLASHING	UPSET	POSTHEAT
Time					
Voltage (Open Circuit)					
Distance at					
Force					
Current					

COMMENTS ____

____

PLATEN TRAVEL INFORMATION ______________________________

TESTING METHODS	REMARKS:
Tension ____________________	
“U” Bend Test ____________________	
Hardness ____________________	
Macro ____________________	

Figure 39—Form for Resistance Welding Data Sheet for Flash or Upset Welding

Table 55
Spot-Welding Parameters for Uncoated AHSS Using AC Welding Machine for IISI Group 3 and 4 Steels

Metal Thickness GMT		Electrode[a, b]		Net Electrode Force	Weld Time Cycles[c]	Cool Time Cycles[c]	Number of Pulses	Hold Time Cycles[c]	Weld Current	Minimum Nugget Diameter
mm	[in]	Face Diameter mm [in]	Shank Diameter mm [in]	N [lbs]	[ms]	[ms]		[ms]	kA	mm [in]
0.70–0.79	[0.028–0.031]	4.8[0.189]	16[0.63]	2140[480]	9[150]	0[0]	1	2[33]	8.0	3.5 [0.138]
0.80–0.99	[0.032–0.038]	4.8[0.189]	16[0.63]	2960[670]	9[150]	0[0]	1	2[33]	8.0	4.0 [0.157]
1.00–1.29	[0.039–0.050]	4.8[0.189]	16[0.63]	2980[670]	10[167]	0[0]	1	2[33]	9.0	4.5 [0.177]
1.30–1.59	[0.051–0.062]	4.8[0.189]	16[0.63]	4230[950]	12[200]	0[0]	1	2[33]	10.0	5.0 [0.197]
1.60–1.89	[0.063–0.074]	4.8[0.189]	19[0.75]	5340[1200]	7[117]	1[17]	2	5[83]	10.5	5.5 [0.217]
1.90–2.29	[0.075–0.090]	4.8[0.189]	19[0.75]	7390[1660]	7[117]	1[17]	3	5[83]	11.5	6.0 [0.236]
2.30–2.69	[0.091–0.105]	4.8[0.189]	19[0.75]	7390[1660]	8[133]	2[33]	3	10[167]	12.0	6.5 [0.256]
2.70–3.00	[0.106–0.118]	4.8[0.189]	19[0.75]	8450[1900]	8[133]	2[33]	3	10[167]	12.5	7.0 [0.276]

[a] Electrodes based on Ball Nose configuration. [RWMA Type "B" dome].
[b] Electrode widths are based on the following: ISO Standards 13, 16, 19, and 22 mm; RWMA Standards 0.48 (0.50), 0.63, 0.75, 0.88, and 1.00 in.
[c] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz equipment, multiply the weld times shown in cycles by 0.83, then round down to the nearest whole number.

Notes:
1. The parameters shown represent a starting point from which a weld schedule can be established.
2. Weld Schedules will produce at least a Minimum Weld Size. Weld Schedule adjustments may be required in production.
3. Maximum 2 thickness stack-up ratio is 1:2.5. Maximum 3 thickness stack-up ratio of adjacent sheets and outer sheets is 1:2.5.
4. 3 thickness total stack-up not to exceed 6.0 mm [0.236 in].

Table 56
Spot-Welding Parameters for Coated AHSS Using AC Welding Machine for IISI Group 3 and 4 Steels

Metal Thickness GMT		Electrode[a,b]		Net Electrode Force	Weld Time Cycles[c]	Cool Time Cycles[c]	Number of Pulses	Hold Time Cycles[c]	Weld Current	Minimum Nugget Diameter
mm	[in]	Face Diameter mm [in]	Shank Diameter mm [in]	N [lbs]	[ms]	[ms]		[ms]	kA	mm [in]
0.70–0.79	[0.028–0.031]	4.8[0.189]	16[0.63]	2140[480]	14[233]	0[0]	1	2[33]	9.0	3.5 [0.138]
0.80–0.99	[0.032–0.038]	4.8[0.189]	16[0.63]	2960[670]	14[233]	0[0]	1	2[33]	9.5	4.0 [0.157]
1.00–1.29	[0.039–0.050]	4.8[0.189]	16[0.63]	2980[670]	16[267]	0[0]	1	2[33]	10.0	4.5 [0.177]
1.30–1.59	[0.051–0.062]	4.8[0.189]	16[0.63]	4230[950]	7[117]	1[17]	3	5[83]	11.0	5.0 [0.197]
1.60–1.89	[0.063–0.074]	4.8[0.189]	19[0.75]	5340[1200]	8[133]	2[33]	3	5[83]	11.5	5.5 [0.217]
1.90–2.29	[0.075–0.090]	4.8[0.189]	19[0.75]	7390[1660]	8[133]	2[33]	4	5[83]	12.5	6.0 [0.236]

[a] Electrodes based on Ball Nose configuration. [RWMA Type "B" dome].
[b] Electrode widths are based on the following: ISO Standards 13, 16, 19, and 22 mm; RWMA Standards 0.48 (0.50), 0.63, 0.75, 0.88, and 1.00 in.
[c] Cycle times shown apply to AC 60 Hz equipment. For 50 Hz equipment, multiply the weld times shown in cycles by 0.83, then round down to the nearest whole number.

Notes:
1. The parameters shown represent a starting point from which a weld schedule can be established.
2. Weld Schedules will produce at least a Minimum Weld Size. Weld Schedule adjustments may be required in production.
3. Maximum 2 thickness stack-up ratio is 1:2.5. Maximum 3 thickness stack-up ratio of adjacent sheets and outer sheets is 1:2.5.
4. 3 thickness total stack-up not to exceed 6.0 mm [0.236 in].

Table 57
Spot-Welding Parameters for Uncoated AHSS Using MFDC Welding Machine for IISI Group 3 and 4 Steels

Metal Thickness GMT		Electrode[a, b]		Net Electrode Force	Weld Time	Hold Time	Weld Current	Minimum Nugget Diameter
mm	[in]	Face Diameter mm [in]	Shank Diameter mm [in]	N[lbs]	[ms]	[ms]	kA	mm [in]
0.70–0.79	[0.028–0.031]	6[0.236]	16[0.63]	2800[630]	210	105	6.5	3.5 [0.138]
0.80–0.99	[0.032–0.038]	6[0.236]	16[0.63]	3400[770]	210	105	7.6	4.0 [0.157]
1.00–1.29	[0.039–0.050]	6[0.236]	16[0.63]	4400[990]	270	135	9.3	4.5 [0.177]
1.30–1.59	[0.051–0.062]	8[0.315]	20[0.75]	5300[1190]	350	175	10.6	5.0 [0.197]
1.60–1.89	[0.063–0.074]	8[0.315]	20[0.75]	6400[1440]	440	220	11.2	5.5 [0.217]
1.90–2.29	[0.075–0.090]	8[0.315]	20[0.75]	7700[1730]	560	280	12.0	6.0 [0.236]
2.30–2.69	[0.091–0.105]	8[0.315]	20[0.75]	8500[1910]	670	335	12.5	6.5 [0.256]
2.70–3.00	[0.106–0.118]	8[0.315]	20[0.75]	10200[2300]	880	440	13.6	7.0 [0.276]

[a] Electrodes based on ISO 5821 Type B configuration. [RWMA Type “F” truncated].
[b] Electrode widths are based on the following: ISO Standards 13, 16, 19, and 22 mm; RWMA Standards 0.48 (0.50), 0.63, 0.75, 0.88, and 1.00 in.

Notes:
1. The parameters shown represent a starting point from which a weld schedule can be established.
2. Weld Schedules will produce at least a Minimum Weld Size. Weld Schedule adjustments may be required in production.
3. Maximum 2 thickness stack-up ratio is 1:2.5. Maximum e thickness stack-up ration of adjacent sheets and outer sheets is 1:2.5.
4. 3 thickness total stack-up not to exceed 6.0 mm [0.236 in].

Table 58
Spot-Welding Parameters for Coated AHSS Using MFDC Welding Machine for IISI Group 3 and 4 Steels

Metal Thickness GMT		Electrode[a, b]		Net Electrode Force	Weld Time	Hold Time	Weld Current	Minimum Nugget Diameter
mm	[in]	Face Diameter mm [in]	Shank Diameter mm [in]	N [lbs]	[ms]	[ms]	kA	mm [in]
0.70–0.79	[0.028–0.031]	6[0.236]	16[0.63]	2800[630]	230	115	7.8	3.5 [0.138]
0.80–0.99	[0.032–0.038]	6[0.236]	16[0.63]	3400[770]	250	125	8.5	4.0 [0.157]
1.00–1.29	[0.039–0.050]	6[0.236]	16[0.63]	4400[990]	310	155	10.1	4.5 [0.177]
1.30–1.59	[0.051–0.062]	8[0.315]	20[0.75]	5300[1190]	400	200	11.5	5.0 [0.197]
1.60–1.89	[0.063–0.074]	8[0.315]	20[0.75]	6400[1440]	480	240	12.4	5.5 [0.217]
1.90–2.29	[0.075–0.090]	8[0.315]	20[0.75]	7700[1730]	600	300	13.2	6.0 [0.236]

[a] Electrodes based on ISO 5821 Type B configuration. [RWMA Type “F” truncated].
[b] Electrode widths are based on the following: ISO Standards 13, 16, 19, and 22 mm; RWMA Standards 0.48 (0.50), 0.63, 0.75, 0.88, and 1.00 in.

Notes:
1. The parameters shown represent a starting point from which a weld schedule can be established.
2. Weld Schedules will produce at least a Minimum Weld Size. Weld Schedule adjustments may be required in production
3. Maximum 2 thickness stack-up ratio is 1:2.5. Maximum e thickness stack-up ration of adjacent sheets and outer sheets is 1:2.5.
4. 3 thickness total stack-up not to exceed 6.0 mm [0.236 in].

Annex A (Informative)
Informative References

This foreword is not part of this standard but is included for informational purposes only.

A1. Welding and Material References

AWS A10.1M, *Specification for Calibration and Performance Testing of Secondary Current Sensing Coils and Weld Current Monitors Used in Single-Phase AC Resistance Welding*, American Welding Society (AWS).

AWS B4.0, *Standard Methods for Mechanical Testing of Welds* (AWS)

AWS C1.4M/C1.4, *Specification for Resistance Welding of Carbon and Low-Alloy Steels*, American Welding Society (AWS).

AWS D8.1M, *Specification for Automotive Weld Quality—Resistance Spot Welding of Steel*, American Welding Society (AWS).

AWS D8.6, *Specification for Automotive Resistance Spot Welding Electrodes*, American Welding Society (AWS).

AWS D8.7M, *Recommended Practices for Automotive Weld Quality—Resistance Spot Welding*, American Welding Society (AWS).

AWS D8.9M, *Recommended Practices for Test Methods for Evaluating the Resistance Spot Welding Behavior of Automotive Sheet Steel Materials*, American Welding Society (AWS).

AWS D17.2M, *Specification for Resistance Welding for Aerospace Applications*, American Welding Society (AWS).

AWS RWPH, *Resistance Welding Pocket Handbook*, American Welding Society (AWS).

Welding Handbook, Ninth Edition, Volume 3, Welding Processes, Part 2, Chapter 1, Resistance Spot and Seam Welding, and Chapter 2, Projection Welding, American Welding Society (AWS).

The Professional's Advisor on Resistance Welding, American Welding Society (AWS).

Welding Aluminum: Theory and Practice, Chapter 13, Resistance Welding, The Aluminum Association.

ASM Handbook, Volume 8, Mechanical Testing, ASM International.

ASTM A568/A568M, Standard Specification for Steel, Sheet, Carbon, and High-Strength, Low-Alloy, Hot-Rolled and Cold-Rolled, General Requirements for, ASTM International.

ASTM E340 and E407, *Annual Book of ASTM Standards*, Vol. 3.01, ASTM International.

Resistance Welder Manufacturers Alliance RWMA Resistance Welding Manual, Revised Fourth Edition, American Welding (AWS).

SAE J1392, *Steel, High Strength, Hot Rolled Sheet and Strip, Cold Rolled Sheet, and Coated Sheet*, SAE International.

Tool and Manufacturing Engineers Handbook, Fourth Edition, Volume 4, Society of Manufacturing Engineers (SME).

A2. Safety References

ANSI/ASSE Z87.1, *Occupational and Educational Personal Eye and Face Protection Devices*, The American Society of Safety Engineers (ASSE).

ANSI/NFPA 70, National *Electrical Code*, National Fire Protection Association (NFPA).

ANSI Z49.1, *Safety in Welding, Cutting and Allied Processes*, American Welding Society (AWS).

ASTM F2413, *Standard Specification for Performance Requirements for Foot Protection*, ASTM International (ASTM).

Effects on Welding and Health, American Welding Society (AWS).

Safety and Health Fact Sheets, American Welding Society (AWS).

Code of Federal Regulations, Title 29 Labor, Chapter XVII, Part 1910, Occupational Safety and Health Standards, Occupational Safety and Health Administration (OSHA).

ANSI Z535.5, *Safety Tags and Barricade Tapes (for Temporary Hazards)*. American National Standards Institute (ANSI).

ANSI Z88.2, *Respiratory Protection*, National Institute for Occupational Safety and Health (NIOSH).

ASME B15.1, *Safety Standard for Mechanical Power Transmission Apparatus*, ASME International.

ISEA/ANSI Z89.1, *Requirements for Protective Headwear for Industrial Workers*, International Safety Equipment Association (ISEA).

NFPA 79, *Electrical Standard for Industrial Machinery*, National Fire Protection Association (NFPA).

Annex B (Informative)
Requesting an Official Interpretation on an AWS Standard

This annex is not part of this standard but is included for informational purposes only.

B1. Introduction

The following procedures are here to assist standard users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

B2. Limitations

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

B3. General Procedure for all Requests

B3.1 Submission. All requests shall be sent to the Managing Director, AWS Standards Development. For efficient handling, it is preferred that all requests should be submitted electronically through standards@aws.org. Alternatively, requests may be mailed to:

Managing Director
Standards Development
American Welding Society
8669 NW 36 St, # 130 Miami,
FL 33166

B3.2 Contact Information. All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

B3.3 Scope. Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1:2006) that contains the provision(s) the inquirer is addressing.

B3.4 Question(s). All requests shall be stated in the form of a question that can be answered "yes" or "no". The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

B3.5 Proposed Answer(s). The inquirer shall provide proposed answer(s) to their own question(s).

B3.6 Background. Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

B4. AWS Policy on Interpretations

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

B5. AWS Response to Requests

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the *Welding Journal*, and post it on the AWS website.

B6. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

List of AWS C1 Documents on Resistance Welding

Designation	Title
AWS C1.1M/C1.1	*Recommended Practices for Resistance Welding*
AWS C1.4M/C1.4	*Specification for Resistance Welding of Carbon- and Low-Alloy Steels*
AWS C1.5	*Specification for the Qualification of Resistance Welding Technicians*

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