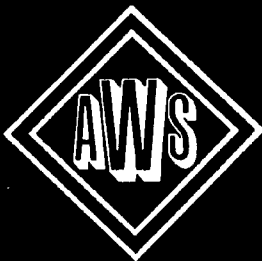


AWS C1.1-66

**Recommended
Practices
for
RESISTANCE
WELDING**



AMERICAN WELDING SOCIETY

AWS C1.1-66

**Recommended
Practices
for
Resistance Welding**

Superseding 1950 Edition

Prepared by
AWS Resistance Welding Committee

Under the Direction of
AWS Technical Activities Committee

Edward A. Fenton
Technical Director

Price \$4.00

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345 East 47th Street, New York, N. Y. 10017

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Note: By publication of these Recommended Practices, the American Welding Society does not insure anyone utilizing these Practices against liability arising from the use of such Practices. A publication of Recommended Practices by the American Welding Society does not carry with it the right to make, use or sell any patented items. Each prospective user should make an independent investigation.

FOREWORD

The data contained in these *Recommended Practices* have been compiled by the AWS Resistance Welding Committee, through its respective subcommittees, 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, tests were conducted to ascertain that welds of the specified strengths could be obtained.

It is important to recognize that these *Recommended Practices* are not presented as the only possible conditions for welding the materials and thicknesses shown; they are rather offered as a guide for setting up welding schedules to be followed in any particular fabrication, modified according to the specific fabricating conditions and production requirements involved.

The present edition of *Recommended Practices* represents an extension of the data presented in earlier editions. New material includes: (1) nine tables covering spot and seam welding of nickel-base alloys, (2) a completely new section covering recommended practices for spot welding magnesium alloys and (3) several additional methods for testing resistance welds. The committee is continuing its activities to provide data for additional materials and to revise and update other portions of the text.

*In using the data shown in the tables it is imperative that reference be made to the appropriate text referred to at the head of each column. 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 comment has been omitted. For more detailed information on the equipment used, the techniques for different materials and joint design for resistance welding consult the Committee publication *Resistance Welding—Theory and Use* and the *AWS Welding Handbook*.*

The AWS Resistance Welding Committee 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 practices 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.

Communications on these *Recommended Practices* will be most welcome. They should be addressed to the Secretary, AWS Resistance Welding Committee, AMERICAN WELDING SOCIETY, 345 East 47th Street, New York, N. Y. 10017.

I. RECOMMENDED PRACTICE FOR SPOT* AND SEAM* WELDING OF

Low-Carbon, Low-Alloy, Medium Carbon and Stainless Steels; Nickel and Nickel-Base Alloys

NOTE: The data on *pulsation welding* should be used only as a guide and are presented for this purpose until such time as more complete information becomes available. The range of thicknesses shown for pulsation welding is not intended to indicate that single-impulse spot welding cannot be used for welding these thicknesses.

101. MATERIAL

These standards apply to the types of material and the thickness ranges shown in the respective tables.

The data on nickel and the nickel-base alloys covered in Tables 1.8 through 1.19 apply to these materials in the annealed condition, but they are also applicable to materials of quarter-hard temper. Following the usage adopted by the ASTM, three proprietary-type nickel-base alloys have been given generic designations. Thus nickel-copper alloy (Ni-Cu) is also known as Monel and by other designations; nickel-chromium-iron alloy (Ni-Cr-Fe) is also known as Inconel and by other designations; and nickel-chromium-iron-titanium alloy (Ni-Cr-Fe-Ti) is inclusive for Inconel "X".

Because special procedures are required for the resistance spot welding of magnesium, Section IV has been devoted to this subject.

102. ELECTRODE DIAMETER AND SHAPE

Two forms of electrode are shown — one having a flat face and beveled sides, the other having a dome-type face. Where the flat-face electrode is used, small diameter d should not exceed the value specified in order to control electrode contact area. On the other hand, use of a much smaller diameter d than specified will cause expulsion and a reduction in weld strength. In use, care should be exercised to prevent excessive increase in d by dressing when required.

Large diameter, D , is a minimum; use of a smaller diameter than specified will result in excessive mushrooming.

The seam welding data are intended for pressure-tight seam welding, hence electrode width, W , rather than diameter is shown.

* The correct terms are "resistance-spot welding" and "resistance-seam welding" because these welds may be made by different welding processes. It should be clear, however, that wherever "spot" or "seam" welding is used in this text, the resistance type is meant.

For spot welding two general formulas are often used in determining small diameter, d , for a given sheet thickness: $d = 2T + 0.1$ in. and $d = \sqrt{T}$. The first has been found more applicable for thinner material, the second for thicker material.

103. NET ELECTRODE, WELD AND TEMPER FORCES

The values shown in the tables refer to the exact force between contact surfaces, such as would be obtained in welding test pieces.

104. TIME

The values shown for all time factors are in cycles based on 60 per second, except that the "Weld Time" for pulsation welding is in pulsations.

"On Times" and "Off Times" for seam welding indicate the time during which the current is flowing and interrupted. If a slower welding speed is necessary, the "Off Time" should be increased to maintain the number of welds per inch, thus preventing an excessive heat input which may cause undue distortion of the work.

105. WELDING CURRENT

The values shown are approximate and are intended to help calculate and specify the capacity of welding machines. They should not be used as exact values to obtain a given weld strength. The current may be increased to the point where metal expulsion occurs and then reduced to just below this point; optimum strengths may thus be obtained.

The data on *Stainless Steels* in Tables 1.5 and 1.7 have been specified in two columns. The first column specifies welding current for steels below 150,000 psi. in tensile strength, the other for steels 150,000 psi. and above.

106. MINIMUM CONTACTING OVERLAP

These values indicate the required overlap as shown in each table. It is extremely important to avoid using overlap below the values specified, otherwise the weld strengths will be difficult to maintain under shop conditions, or distortion of the lapping sheets may occur.

107. MINIMUM WELD SPACING

The weld spacings specified should be maintained so that no special precautions need be taken to compensate for the shunted current effect of adjacent welds.

108. DIAMETER OF FUSED ZONE

These data are helpful when cross-sectional etch tests are made to check penetration of the weld.*

* See "Standard Methods for Testing Resistance Welds," page 89, for description of Macro-etch Test.

109. MINIMUM SHEAR AND TENSILE STRENGTHS

Tension-Shear and Cross-Tension Tests in a reliable testing machine, with the samples unconfined, are the accepted methods of checking these values.[†] Welds made during the setting up of a machine should never be used to establish these shear and tensile strengths. Only those welds made after the machine has been properly adjusted should be considered in the evaluation.

In considering weld strength, it should be recognized that variations in individual weld strengths exist no matter how accurately the welding variables are controlled. Shop strength, which determines the acceptable machine setting, should therefore be above the minimum value indicated. How much above should be determined by test and experience; as a guide it should be set sufficiently above the values indicated (approximately 20%) so that no welds will fall below the indicated minimum values when tested.*

The data for seam welding are intended to produce pressure-tight welds which will not fail before failure of the material and no definite strengths are specified.**

The data for *Stainless Steels* in Tables 1.5 and 1.7 have been furnished for these steels cold rolled to three different tempers: Values specified for steels having a tensile strength from 70,000 up to 90,000 psi., are applicable to dead soft steel, regardless of type. Values specified for steels having a tensile strength from 90,000 up to 150,000 psi., are applicable to low-tensile ‡ and one-quarter hard steel. Values specified for steels having a tensile strength 150,000 psi. and higher are applicable to one-half and up to full hard steels.

The data are based on the intimate contact of plane surfaces. If the contacting surfaces are not flat, the shear strength will be below the values shown.

[†] See "Standard Methods for Testing Resistance Welds," pages 79 and 81, for standard procedures for Tension-Shear and Cross-Tension Tests.

* Control of weld strength is often maintained by statistical analysis which is discussed in the "Standard Methods for Testing Resistance Welds," page 104.

** See "Standard Methods for Testing Resistance Welds," page 91 for Pillow Test for seam welds.

‡ Low-tensile steel is dead soft steel that has had a cold pass after final annealing to give the sheet or strip more flatness.

Table 1.1—Spot Welding Low-Carbon Steel

THICKNESS "T" OF THINNEST OUTSIDE PIECE (SEE PAR. 101 AND NOTES 1, 2, 3 AND 4 BELOW)	ELECTRODE DIAMETER AND SHAPE (SEE PAR. 102 AND NOTE 5 BELOW)	NET ELECTRODE FORCE (SEE PAR. 103)	WELD TIME (SINGLE IMPULSE) (SEE PAR. 104)	WELDING CURRENT (APPROX.) (SEE PAR. 105)	MINIMUM CONTACTING OVERLAP (SEE PAR. 106)	MINIMUM WELD SPACING (SEE PAR. 107 AND NOTE 6 BELOW)	DIAMETER OF FUSED ZONE (SEE PAR. 108)	MINIMUM SHEAR STRENGTH (SEE PAR. 109)		THICKNESS "T" OF THINNEST OUTSIDE PIECE (SEE PAR. 101 AND NOTES 1, 2, 3 AND 4 BELOW)
INCHES	D, IN., MIN. MAX.	LB.	CYCLES (60 PER SEC.)	AMPS	IN.	IN.	IN., APPROX.	ULTIMATE STRENGTH OF METAL TENSILE STRENGTH BELOW 70000 PSI AND ABOVE	TENSILE STRENGTH 70000 PSI AND ABOVE	
0.010	3/8 1/8	200	4	4000	3/8	1/4	0.10	130	180	0.010
0.021	3/8 3/16	300	6	6500	7/16	3/8	0.13	320	440	0.021
0.031	3/8 3/16	400	8	8000	7/16	1/2	0.16	570	800	0.031
0.040	1/2 1/4	500	10	9500	1/2	3/4	0.19	920	1200	0.040
0.050	1/2 1/4	650	12	10500	9/16	7/8	0.22	1350	—	0.050
0.062	1/2 1/4	800	14	12000	5/8	1	0.25	1850	—	0.062
0.078	5/8 5/16	1100	17	14000	11/16	1 1/4	0.29	2700	—	0.078
0.094	5/8 5/16	1300	20	15500	3/4	1 1/2	0.31	3450	—	0.094
0.109	5/8 3/8	1600	23	17500	13/16	1 5/8	0.32	4150	—	0.109
0.125	7/8 3/8	1800	26	19000	7/8	1 3/4	0.33	5000	—	0.125

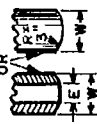
NOTES:

1. TYPE OF STEEL — SAE 1010
2. MATERIAL SHOULD BE FREE FROM SCALE, OXIDES, PAINT, GREASE AND OIL
3. WELDING CONDITIONS DETERMINED BY THICKNESS OF THINNEST OUTSIDE PIECE "T"
4. DATA FOR TOTAL THICKNESS OF PILE-UP NOT EXCEEDING 4 "T". MAXIMUM RATIO BETWEEN TWO THICKNESSES 3 TO 1
5. ELECTRODE MATERIAL, CLASS 2
MINIMUM CONDUCTIVITY — 75% OF COPPER
MINIMUM HARDNESS — 75 ROCKWELL "B"
6. MINIMUM WELD SPACING IS THAT SPACING FOR TWO PIECES FOR WHICH NO SPECIAL PRECAUTIONS NEED BE TAKEN TO COMPENSATE FOR SHUNTED CURRENT EFFECT OF ADJACENT WELDS. FOR THREE PIECES INCREASE SPACING 30 PER CENT.

Spot and Seam Welding

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Table 1.2—Seam Welding Low-Carbon Steel

THICKNESS "T" OF THINNEST OUTSIDE PIECE (SEE PAR. 101 AND NOTES 1, 2, 3 AND 4 BELOW)	ELECTRODE WIDTH AND SHAPE (SEE PAR. 102 AND NOTE 5 BELOW) 		NET ELECTRODE FORCE (SEE PAR. 103)	ON TIME (SEE PAR. 104) CYCLES (60 PER SEC.)	OFF TIME (PRESSURE— TIGHT) (SEE PAR. 104) CYCLES	WELD SPEED (SEE PAR. 104) IN. PER MIN.	WELDS PER INCH (SEE PAR. 104)	WELDING CURRENT (APPROX.) (SEE PAR. 105) AMPS	MINIMUM CONTACTING OVERLAP (SEE PAR. 106 AND NOTE 6 BELOW) 	THICKNESS "T" OF THINNEST OUTSIDE PIECE (SEE PAR. 101 AND NOTES 1, 2, 3 AND 4 BELOW)
	W, IN., MIN.	E, IN., MAX.								
0.010	3/8	3/16	400	2	1	80	15	8000	3/8	0.010
0.021	3/8	3/16	550	2	2	75	12	11000	7/16	0.021
0.031	1/2	1/4	700	3	2	72	10	13000	1/2	0.031
0.040	1/2	1/4	900	3	3	67	9	15000	1/2	0.040
0.050	1/2	5/16	1050	4	3	65	8	16500	9/16	0.050
0.062	1/2	5/16	1200	4	4	63	7	17500	5/8	0.062
0.078	5/8	3/8	1500	6	5	55	6	19000	11/16	0.078
0.094	5/8	7/16	1700	7	6	50	5.5	20000	3/4	0.094
0.109	3/4	1/2	1950	9	6	48	5	21000	13/16	0.109
0.125	3/4	1/2	2200	11	7	45	4.5	22000	7/8	0.125

NOTES:

1. TYPE OF STEEL—SAE 1010
2. MATERIAL SHOULD BE FREE FROM SCALE, OXIDES, PAINT, GREASE AND OIL
3. WELDING CONDITIONS DETERMINED BY THICKNESS OF THINNEST OUTSIDE PIECE "T"
4. DATA FOR TOTAL THICKNESS OF PILE-UP NOT EXCEEDING 4 "T". MAXIMUM RATIO BETWEEN THICKNESSES 3 TO 1
5. ELECTRODE MATERIAL, CLASS 2
MINIMUM CONDUCTIVITY — 75% OF COPPER
MINIMUM HARDNESS — 75 ROCKWELL "B"
6. FOR LARGE ASSEMBLIES MINIMUM CONTACTING OVERLAP INDICATED SHOULD BE INCREASED 30 PER CENT

Table 1.3—Pulsation Welding Low-Carbon Steel

COMBINATION OF THICKNESSES TO BE WELDED (NOTES 1 AND 2 (SEE PAR. 101 AND NOTES 1 AND 2 BELOW))	ELECTRODE DIAMETER AND SHAPE (SEE PAR. 102 AND NOTE 3 BELOW)	NET ELECTRODE FORCE (SEE PAR. 103)	WELD TIME		WELDING CURRENT (APPROX.) (SEE PAR. 105)	MINIMUM CONTACTING OVERLAP (SEE PAR. 106)	MINIMUM DIAMETER OF FUSED ZONE (SEE PAR. 108)	MINIMUM SHEAR STRENGTH OF TENSILE STRENGTH LESS THAN 70,000 PSI (SEE PAR. 109)	COMBINATION OF THICKNESSES TO BE WELDED (SEE PAR. 101 AND NOTES 1 AND 2 BELOW)			
			ON 20 CYCLES (60 PER SEC.) (SEE PAR. 104)	OFF 5 CYCLES (60 PER SEC.) (SEE PAR. 104)					T-1	T-2		
											NO. OF PULSATIONS	
											SINGLE WELDS	ADJACENT WELDS
		LB.	1 IN. TO 2 IN. CENTERS	2 IN. TO 4 IN. CENTERS	AMPS	IN.	IN. APPROX.	LB.	T-1	T-2		
1/8	1	7/16	3	5	4	18000	7/8	3/8	5000	1/8	1/8	
1/8	1	7/16	3	5	4	18000	7/8	3/8	5000	1/8	3/16	
1/8	1	7/16	3	5	4	18000	7/8	3/8	5000	1/8	1/4	
3/16	1 1/4	1/2	6	20	14	19500	1 1/8	9/16	10000	3/16	3/16	
3/16	1 1/4	1/2	6	20	14	19500	1 1/8	9/16	10000	3/16	1/4	
3/16	1 1/4	1/2	6	20	14	19500	1 1/8	9/16	10000	3/16	5/16	
1/4	1 1/4	9/16	12	24	18	21500	1 3/8	3/4	15000	1/4	1/4	
1/4	1 1/4	9/16	12	24	18	21500	1 3/8	3/4	15000	1/4	5/16	
5/16	1 1/2	5/8	15	30	23	24000	1 1/2	7/8	20000	5/16	5/16	

NOTES :

1. TYPE OF STEEL – SAE 1010

2. MATERIAL SHOULD BE FREE FROM SCALE, OXIDE, PAINT, GREASE AND OIL

3. ELECTRODE MATERIAL,

CLASS 2

MINIMUM CONDUCTIVITY – 75 % OF COPPER

MINIMUM HARDNESS – 75 ROCKWELL "B"

NOTES :

1. TYPE OF STEEL — SAE 1010
2. MATERIAL SHOULD BE FREE FROM SCALE, OXIDE, PAINT, GREASE AND OIL
3. ELECTRODE MATERIAL, CLASS 2
MINIMUM CONDUCTIVITY — 75 % OF COPPER
MINIMUM HARDNESS — 75 ROCKWELL "B"

Spot and Seam Welding

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Table 1.4—Spot Welding Low-Alloy and Medium Carbon Steels

MATERIAL (SEE PAR. 101 AND NOTES 1, 2, 3 AND 4 BELOW)		ELECTRODE DIAMETER AND SHAPE (SEE PAR. 102 AND NOTES 3 AND 4)			NET ELECTRODE WELD AND TEMPER FORCE (SEE PAR. 103)	WELD TIME (SEE PAR. 104)	QUENCH TIME (SEE PAR. 104)	TEMPER TIME (SEE PAR. 104)	WELDING CURRENT (APPROX.) (SEE PAR. 105)	TEMPER CURRENT (SEE PAR. 106)	MINIMUM CONTACTING OVERLAP (SEE PAR. 107 AND NOTE 5 BELOW)	DIAMETER OF FUSED ZONE (SEE PAR. 108)	MINIMUM WELD STRENGTH (SEE PAR. 109)		RATIO TENSILE SHEAR STRENGTH
		TYPE	CONDITION	"T" THICKNESS INCHES	D INCHES MIN.	d INCHES	R INCHES	LBS.	CYCLES (60 PER SEC.)	CYCLES (60 PER SEC.)	% OF WELDING CURRENT	IN.	SHEAR STRENGTH LBS.	TENSILE STRENGTH LBS.	PERCENT
SAE 1020		HOT ROLLED	0.040	5/8	1/4	6	1475	6	16 000	90	1/2	1	1360	920	68
								6	14 200	91	1/2	1	1560	920	59
								6	13 900	80	1/2	1	2000	680	33
								6	13 000	90	1/2	1	2120	640	30
SAE 4340		HOT ROLLED	0.031	5/8	3/16	6	900	4	8 250	84	7/16	3/4	1084	280	27
								4	13 900	77	5/8	1 1/2	3540	1440	37
								10	21 800	86	7/8	2 1/2	13 880	4000	29
								4	8 650	80	7/16	3/4	1220	524	43
SAE 8630		HOT ROLLED	0.062	5/8	5/16	6	1800	10	12 800	83	5/8	1 1/2	4240	2200	52
								45	21 800	84	7/8	2 1/2	13 500	4500	34
								4	3 900	85	7/16	5/8	400	800	50
								10	12 250	85	5/8	1 1/2	3300	1800	55
SAE 8715		HOT ROLLED	0.125	5/8	1	10	4500	45	22 700	85	7/8	2 1/2	12 760	4 500	35
								6	10 000	79	1/2	1	1640	1020	61
								6	12 400	79	1/2	1	2040	1020	60
								8	22 600	67	1 1/16	1 7/8	4250	2800	66
SAE 9115		HOT ROLLED	0.070	3/4	11/32	6	2800	8	22 600	71	1 1/16	1 7/8	5050	2560	50
								8	10 000	79	1/2	1	1640	1020	61
								6	12 400	79	1/2	1	2040	1020	60
								8	22 600	67	1 1/16	1 7/8	4250	2800	66
SAE 9115		HOT ROLLED	0.070	3/4	11/32	6	2800	8	22 600	71	1 1/16	1 7/8	5050	2560	50
								8	10 000	79	1/2	1	1640	1020	61
								6	12 400	79	1/2	1	2040	1020	60
								8	22 600	67	1 1/16	1 7/8	4250	2800	66

NOTES:

1. MATERIAL SHOULD BE PICKLED OR OTHERWISE CLEANED TO OBTAIN A SURFACE CONTACT RESISTANCE NOT EXCEEDING 200 MICRONS.
2. DATA IS FOR TWO PIECES OF EQUAL THICKNESS, EACH OF THICKNESS "T".
3. ELECTRODE MATERIAL: RWMA CLASS 2 MINIMUM ELECTRICAL CONDUCTIVITY - 75% OF COPPER, MINIMUM HARDNESS 75 ROCKWELL B
4. ELECTRODE DIAMETER & SHAPE ARE THE SAME FOR BOTH UPPER AND LOWER ELECTRODES.
5. MINIMUM SPACING IS THAT SPACING FOR WHICH NO SPECIAL PRECAUTIONS NEED BE TAKEN TO COMPENSATE FOR SHUNTED CURRENT EFFECT OF ADJACENT WELDS.

Table 1.5—Spot Welding Stainless Steels

THICKNESS OF THINNEST OUTSIDE PIECE (SEE PAR. 101 AND NOTES 1, 2, 3 AND 4 BELOW)	ELECTRODE DIAMETER AND SHAPE (SEE PAR. 102 AND NOTE 5)		NET ELECTRODE FORCE (SEE PAR. 103)	WELD TIME (SINGLE IMPULSE) (SEE PAR. 104)	WELDING CURRENT (APPROX.) (SEE PAR. 106)	MINIMUM CONTACTING OVERLAP (SEE PAR. 109) (NOTE 6 BELOW)	MINIMUM WELD SPACING (SEE PAR. 108 AND NOTE 6 BELOW)	DIAMETER OF FUSED ZONE (SEE PAR. 107)	MINIMUM SHEAR STRENGTH (SEE PAR. 105)		THICKNESS OF THINNEST OUTSIDE PIECE (SEE PAR. 101 AND NOTES 1, 2, 3 AND 4 BELOW)
	D, IN., MIN.	d, IN., MAX.							LB.	ULTIMATE TENSILE STRENGTH OF METAL 70000 PSI UP TO 90000 PSI AND HIGHER	
0.006	3/16	5/32	180	2	2000	3/16	3/16	0.045	60	70	0.006
0.008	3/16	3/16	200	3	2000	3/16	3/16	0.055	100	130	0.008
0.010	3/16	1/8	230	3	2000	3/16	3/16	0.065	150	210	0.010
0.012	1/4	1/8	280	3	2100	1/4	1/4	0.076	185	250	0.012
0.014	1/4	1/8	300	4	2500	1/4	1/4	0.082	240	320	0.014
0.016	1/4	1/8	330	4	3000	1/4	1/4	0.088	280	300	0.016
0.018	1/4	1/8	380	4	3500	1/4	1/4	0.093	320	360	0.018
0.021	1/4	5/32	400	4	4000	3/16	3/16	0.100	370	470	0.021
0.025	3/8	5/32	520	5	5000	3/8	3/8	0.120	500	800	0.025
0.031	3/8	3/16	650	5	6000	3/8	1/2	0.130	680	800	0.031
0.034	3/8	3/16	750	6	7000	1/2	1/2	0.150	800	920	0.034
0.040	3/8	3/16	900	6	7800	1/2	1/2	0.160	1000	1270	0.040
0.044	3/8	3/16	1000	8	8700	1/2	1/2	0.180	1200	1450	0.044
0.050	1/2	1/4	1200	8	9500	1/2	3/4	0.190	1450	1700	0.050
0.056	1/2	1/4	1350	10	10300	9/16	3/4	0.210	1700	2000	0.056
0.082	1/2	1/4	1500	10	11000	5/8	1	0.230	1950	2400	0.082
0.070	5/8	1/4	1700	12	12300	5/8	1 1/8	0.250	2400	2800	0.070
0.078	5/8	5/16	1900	14	14000	1 1/8	1 1/8	0.275	2700	3400	0.078
0.084	5/8	5/16	2400	16	15700	3/4	1 1/8	0.285	3550	4200	0.084
0.109	3/4	3/8	2800	18	17700	1 1/8	1 1/2	0.290	4200	5000	0.109
0.125	3/4	3/8	3300	20	18000	1 1/8	2	0.300	5000	6000	0.125

NOTES:

1. TYPES OF STEEL — 301, 302, 304, 306, 309, 310, 316, 317, 321, 347 AND 349
2. MATERIAL SHOULD BE FREE FROM SCALE, OXIDES, PAINT, GREASE AND OIL
3. WELDING CONDITIONS DETERMINED BY THICKNESS OF THINNEST OUTSIDE PIECE "T"
4. DATA FOR TOTAL THICKNESS OF PILE-UP NOT EXCEEDING 4 WT% MAXIMUM RATIO BETWEEN TWO THICKNESSES 3 TO 1
5. ELECTRODE MATERIAL, CLASS 2, CLASS 3 OR CLASS 11
MINIMUM CONDUCTIVITY — 75%
MINIMUM HARDNESS — 75
MINIMUM ROCKWELL "B" — 95
30% OF COPPER
6. MINIMUM WELD SPACING IS THAT SPACING FOR TWO PIECES FOR WHICH NO SPECIAL PRECAUTIONS NEED BE TAKEN TO COMPENSATE FOR SHUNTED CURRENT EFFECT OF ADJACENT WELDS. FOR THREE PIECES INCREASE SPACING 30 PER CENT

Spot and Seam Welding

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Table 1.6—Seam Welding Stainless Steels

THICKNESS "T" OF THINNEST OUTSIDE PIECE (SEE PAR. 101 AND NOTES 1, 2, 3 AND 4 BELOW)	ELECTRODE WIDTH AND SHAPE (SEE PAR. 102 AND NOTE 5 BELOW)	NET ELECTRODE FORCE (SEE PAR. 103)	ON TIME (SEE PAR. 104)	CYCLES (60 PER SEC.)				OFF TIME FOR MAXIMUM SPEED (PRESSURE - TIGHT) (SEE PAR. 104)				MAXIMUM WELD SPEED (SEE PAR. 104)	WELDS PER INCH (SEE PAR. 104)				WELDING CURRENT (APPROX.) (SEE PAR. 105)	MINIMUM CONTACTING OVERLAP (SEE PAR. 106 AND NOTE 6 BELOW)	THICKNESS "T" OF THINNEST OUTSIDE PIECE (SEE PAR. 101 AND NOTES 1, 2, 3 AND 4 BELOW)
				CYCLES		CYCLES		CYCLES		CYCLES									
				2 "T"	4 "T"	2 "T"	4 "T"	2 "T"	4 "T"	2 "T"	4 "T"								
INCHES	W, IN., MIN.	LB.	(60 PER SEC.)	2 "T"	4 "T"	2 "T"	4 "T"	2 "T"	4 "T"	2 "T"	4 "T"	AMPS.	IN.	INCHES					
0.006	3/16	300	2	1	1	1	1	60	67	20	18	4000	1/4	0.006					
0.008	3/16	350	2	1	1	2	2	67	56	18	16	4600	1/4	0.008					
0.010	3/16	400	3	2	2	2	2	45	51	16	14	5000	1/4	0.010					
0.012	1/4	450	3	2	2	2	2	48	55	15	13	5600	5/16	0.012					
0.014	1/4	500	3	2	2	2	3	51	46	14	13	6200	5/16	0.014					
0.016	1/4	600	3	2	2	2	3	51	50	14	12	6700	5/16	0.016					
0.018	1/4	650	3	2	2	2	3	55	50	13	12	7300	5/16	0.018					
0.021	1/4	700	3	2	2	2	3	55	55	13	11	7900	3/8	0.021					
0.025	3/8	850	3	3	3	3	4	50	47	12	11	9200	7/16	0.025					
0.031	3/8	1000	3	3	3	3	4	50	47	12	11	10600	7/16	0.031					
0.040	3/8	1300	3	4	4	4	5	47	45	11	10	13000	1/2	0.040					
0.050	1/2	1600	4	4	4	4	5	45	44	10	9	14200	5/8	0.050					
0.062	1/2	1850	4	4	4	5	7	40	41	10	8	15100	5/8	0.062					
0.070	5/8	2150	4	5	5	7	7	44	41	9	8	15900	11/16	0.070					
0.078	5/8	2300	4	6	6	7	7	40	41	9	8	16500	11/16	0.078					
0.094	5/8	2550	5	6	6	7	7	36	38	9	8	16600	3/4	0.094					
0.109	3/4	2950	5	7	7	9	9	38	37	8	7	16800	13/16	0.109					
0.125	3/4	3300	6	6	6	8	8	38	37	8	7	17000	7/8	0.125					

NOTES:

1. TYPES OF STEEL - 301, 302, 303, 304, 308, 309, 310, 316, 317, 321, 347 AND 349
2. MATERIAL SHOULD BE FREE FROM SCALE, OXIDES, PAINT, GREASE AND OIL
3. WELDING CONDITIONS DETERMINED BY THICKNESS OF THINNEST OUTSIDE PIECE "T"
4. DATA FOR TOTAL THICKNESS OF PILE-UP NOT EXCEEDING 4 "T" MAXIMUM RATIO BETWEEN THICKNESSES 3 TO 1
5. ELECTRODE MATERIAL, CLASS 3
MINIMUM CONDUCTIVITY - 45% OF COPPER
MINIMUM HARDNESS - 95 ROCKWELL "B"
6. FOR LARGE ASSEMBLIES MINIMUM CONTACTING OVERLAP INDICATED SHOULD BE INCREASED 30 PER CENT

Table 1.7—Pulsation Welding Stainless Steels

THICKNESS "T" OF THINNEST OUTSIDE PIECE (SEE PAR. 101 AND NOTES 1, 2, 3 AND 4 BELOW)	ELECTRODE DIAMETER AND SHAPE (SEE PAR. 102 AND NOTE 5 BELOW)	NET ELECTRODE FORCE (SEE PAR. 103)	WELD TIME ON 15 OFF 6 CYCLES (60 PER SEC.) (SEE PAR. 104)	WELDING CURRENT (APPROX.) (SEE PAR. 105)		MINIMUM CONTACTING OVERLAP (SEE PAR. 106)	MINIMUM WELD SPACING (SEE PAR. 107 AND NOTE 6 BELOW)	MINIMUM DIAMETER OF FUSED ZONE (SEE PAR. 108)	MINIMUM SHEAR STRENGTH (SEE PAR. 109)	THICKNESS "T" OF THINNEST OUTSIDE PIECE (SEE PAR. 101 AND NOTES 1, 2, 3 AND 4 BELOW)		
				AMPS.								
				BASE METAL TENSILE STRENGTH BELOW 150000 PSI 150000 PSI AND HIGHER	90000 UP TO 150000 PSI AND HIGHER							
INCHES	D, IN., MIN.	d, IN., MAX.	NO. OF PULSATIONS	LB.		IN.	IN.	IN.	LB.	INCHES		
0.156	1	1/2	4	4000	20700	17500	1 1/4	1 7/8	0.440	7600	10000	0.156
0.187	1	1/2	5	5000	21500	18500	1 1/2	2	0.500	9750	12300	0.187
0.203	1	5/8	6	5500	22000	19000	1 5/8	2 1/8	0.530	10600	13000	0.203
0.250	1	5/8	7	7000	22500	20000	1 3/4	2 3/8	0.600	13500	17000	0.250

NOTES:

1. TYPES OF STEEL - 301, 302, 303, 304, 308, 309, 310, 316, 317, 321, 347 AND 349

2. MATERIAL SHOULD BE FREE FROM SCALE, OXIDES, PAINT, GREASE AND OIL

3. WELDING CONDITIONS DETERMINED BY THICKNESS OF THINNEST OUTSIDE PIECE "T"

4. DATA FOR TOTAL THICKNESS OF PILE-UP NOT EXCEEDING 4 "T". MAXIMUM RATIO BETWEEN TWO THICKNESSES 3 TO 1

5. ELECTRODE MATERIAL, CLASS 3 OR CLASS II
MINIMUM CONDUCTIVITY - 45% 30% OF COPPER
MINIMUM HARDNESS - 95 98 ROCKWELL "B"

6. MINIMUM WELD SPACING IS THAT SPACING FOR TWO PIECES WHICH NO SPECIAL PRECAUTIONS NEED BE TAKEN TO COMPENSATE FOR SHUNTED CURRENT EFFECT OF ADJACENT WELDS. FOR THREE PIECES INCREASE SPACING 30 PER CENT

NOTES:

1. TYPES OF STEEL - 301, 302, 303, 304, 308, 309, 310, 316, 317, 321, 347 AND 349
2. MATERIAL SHOULD BE FREE FROM SCALE, OXIDES, PAINT, GREASE AND OIL
3. WELDING CONDITIONS DETERMINED BY THICKNESS OF THINNEST OUTSIDE PIECE "T"
4. DATA FOR TOTAL THICKNESS OF PILE-UP NOT EXCEEDING 4 "T". MAXIMUM RATIO BETWEEN TWO THICKNESSES 3 TO 1
5. ELECTRODE MATERIAL, CLASS 3 OR CLASS II
MINIMUM CONDUCTIVITY - 45% 30% OF COPPER
MINIMUM HARDNESS - 95 98 ROCKWELL "B"
6. MINIMUM WELD SPACING IS THAT SPACING FOR TWO PIECES WHICH NO SPECIAL PRECAUTIONS NEED BE TAKEN TO COMPENSATE FOR SHUNTED CURRENT EFFECT OF ADJACENT WELDS. FOR THREE PIECES INCREASE SPACING 30 PER CENT

Table 1.8—Spot Welding Annealed Ni-Cu* on Single-Phase Equipment

MATERIAL THICKNESS (SEE PAR. 101 AND NOTE 1 BELOW)	ELECTRODE DIAMETER (SEE PAR. 102 AND NOTES 2 AND 3 BELOW)		NET ELECTRODE FORCE (SEE PAR. 103)	WELD TIME (SEE PAR. 104)	WELDING CURRENT (APPROX.) (SEE PAR. 105)	MINIMUM CONTACTING OVERLAP (SEE PAR. 106)	MINIMUM WELD SPACING (SEE PAR. 107 AND NOTE 4 BELOW)	DIAMETER FUSED ZONE (SEE PAR. 108)	MINIMUM SHEAR STRENGTH (SEE PAR. 109)	MATERIAL THICKNESS (SEE PAR. 101 AND NOTE 1 BELOW)
INCHES	d, IN., MAX.	D, IN., MIN.	LBS	CYCLES (60 PER SEC.)	AMPS	IN	IN	IN	LBS	INCHES
0.005 TO:										0.005 TO:
0.005	5/32	5/32	220	2	5,000	1/4	1/4	0.10	55	0.005
0.010	5/32	5/32	220	2	6,100	1/4	1/4	0.10	60	0.010
0.015	5/32	5/32	220	2	7,000	1/4	5/16	0.10	75	0.015
0.021	5/32	1/4	220	3	7,200	1/4	3/8	0.11	85	0.021
0.031	5/32	1/4	250	4	7,400	1/4	3/8	0.11	95	0.031
0.063	5/32	5/8	250	4	8,000	1/4	7/16	0.11	90	0.063
0.094	5/32	5/8	250	4	8,600	1/4	1/2	0.11	90	0.094
0.125	5/32	5/8	250	4	8,700	1/4	1/2	0.11	85	0.125
0.010 TO:										0.010 TO:
0.010	5/32	5/32	270	2	7,200	1/4	1/4	0.12	145	0.010
0.015	5/32	5/32	280	2	8,600	1/4	5/16	0.12	155	0.015
0.021	5/32	5/32	280	3	8,200	1/4	5/16	0.13	170	0.021
0.031	5/32	5/32	300	4	8,800	1/4	3/8	0.13	190	0.031
0.063	5/32	5/16	300	4	9,200	1/4	7/16	0.13	190	0.063
0.094	5/32	5/8	325	4	9,900	1/4	1/2	0.14	210	0.094
0.125	5/32	5/8	325	4	9,900	1/4	1/2	0.14	220	0.125
0.015 TO:										0.015 TO:
0.015	3/16	3/16	300	2	8,600	1/4	5/16	0.13	250	0.015
0.021	3/16	3/16	300	6	8,200	1/4	3/8	0.13	295	0.021
0.031	3/16	3/16	325	6	9,300	1/4	3/8	0.13	300	0.031
0.063	3/16	5/8	325	6	9,400	1/4	7/16	0.14	350	0.063
0.093	3/16	5/8	325	8	9,500	1/4	1/2	0.14	360	0.093
0.125	3/16	5/8	325	8	9,500	1/4	1/2	0.14	365	0.125
0.021 TO:										0.021 TO:
0.021	3/16	3/16	300	12	6,200	5/16	7/16	0.13	450	0.021
0.031	3/16	3/16	325	12	6,800	5/16	7/16	0.13	460	0.031
0.063	3/16	5/16	325	12	7,200	5/16	1/2	0.14	500	0.063
0.093	3/16	5/8	325	12	7,700	3/8	9/16	0.14	530	0.093
0.125	3/16	5/8	325	12	8,200	3/8	9/16	0.14	550	0.125
0.031 TO:										0.031 TO:
0.031	3/16	3/16	700	12	10,500	3/8	5/8	0.17	845	0.031
0.063	3/16	1/4	750	12	11,200	1/2	11/16	0.18	910	0.063
0.094	3/16	5/8	775	12	11,400	1/2	3/4	0.19	1035	0.094
0.125	3/16	5/8	775	12	11,800	1/2	3/4	0.19	1075	0.125
0.063 TO:										0.063 TO:
0.063	5/16	5/16	2700	12	15,300	5/8	1-1/8	0.31	2060	0.063
0.093	5/16	5/8	2700	12	15,900	5/8	1-3/16	0.31	2180	0.093
0.125	5/16	5/8	2700	12	16,200	5/8	1-1/4	0.32	2360	0.125
0.093 TO:										0.093 TO:
0.093	3/8	3/8	2760	20	22,600	3/4	1-1/4	0.37	3680	0.093
0.125	3/8	3/8	2760	20	25,000	3/4	1-1/4	0.38	4390	0.125
0.125 TO:										0.125 TO:
0.125	1/2	1/2	5000	30	30,000	7/8	1-5/8	0.47	5850	0.125

NOTES.

- MATERIAL SHOULD BE FREE FROM SCALE, OXIDES, PAINT, GREASE AND OIL.
- ELECTRODE SHAPE MAY BE FLAT RATHER THAN DOME, IN WHICH CASE THE SHEAR STRENGTHS AND NUGGET DIAMETERS WILL BE HIGHER AND LARGER THAN SHOWN IN THE TABLE.
- ELECTRODE MATERIALS, CLASS 1 OR CLASS 2
MINIMUM CONDUCTIVITY 80% Cu 75% Cu
MINIMUM HARDNESS 68 Rb 75 Rb
- MINIMUM WELD SPACING IS THAT SPACING FOR TWO PIECES FOR WHICH NO SPECIAL PRECAUTIONS NEED BE TAKEN TO COMPENSATE FOR SHUNTED CURRENT EFFECT OF ADJACENT WELDS.
FOR THREE PIECES INCREASE SPACING 30 PERCENT.

*COMMONLY KNOWN AS MONEL

Table 1.9—Seam Welding Annealed Ni-Cu* on Single-Phase Equipment

THICKNESS "T" OF THINNEST OUTSIDE PIECE (SEE PAR. 101 AND NOTES 1 AND 2 & 3 BELOW)	ELECTRODE WIDTH AND SHAPE (SEE PAR. 102 AND NOTE 4 BELOW)		NET ELECTRODE FORCE (SEE PAR. 103)	ON TIME (SEE PAR. 104)	OFF TIME (PRESSURE TIGHT) (SEE PAR. 104)	WELD SPEED (SEE PAR. 104)	WELDS PER INCH (SEE PAR. 104)	WELDING CURRENT (APPROX.) (SEE PAR. 105)	MINIMUM CONTACTING OVERLAP (SEE PAR. 106)
	W, IN. MIN.	E, IN. MAX.							
0.010 BURNISHED** ELECTRODES	3/8	5/32	3	1	3	75	12	5,300	1/4
0.015 BURNISHED ELECTRODES	3/8	5/32	6	1	3	75	12	7,600	1/4
0.021 UNBURNISHED ELECTRODES	3/8	3/16	6	2	6	38	12	8,700	5/16
0.025 UNBURNISHED ELECTRODES	3/8	3/16	6	3	12	20	12	9,500	5/16
0.031	3/8	3/16	6	4	12	19	12	10,000	3/8
0.062	1/2	3/8	6	8	12	20	9	19,000	5/8

* Commonly known as Monel

** Burnishing is a method of surface finishing used mainly to improve the coined finish on the electrode face. It consists of rolling the electrode face to the desired shape until the surface becomes smooth, somewhat hardened and accurately shaped.

Notes:

1. Material should be free from scale, oxides, paint, grease and oil.
2. Welding conditions determined by thickness of thinnest outside piece "t".
3. Data for total thickness of pile-up not exceeding 4 "t". Maximum ratio between thicknesses 3 to 1.
4. Electrode Material RWMA Class 2 (preferred) or 80% I.A.C.S. Minimum Conductivity 754 I.A.C.S. Minimum Hardness 75 Rockwell B (for forgings)

Table 1.10—Spot Welding Annealed Ni-Cu* on Three-Phase Frequency-Converter Machines

MATERIAL THICKNESS (see par. 101 and note 1, 2 & 3 below)	ELECTRODE DIAMETER AND SHAPE (see par. 102 and notes 4 & 6 below)			NET ELECTRODE FORCE (see par. 103)	WELD TIME (see par. 104 and note 7 below)		WELDING CURRENT APPROX. (see par. 105)	MINIMUM CONTACT OVERLAP (see par. 106)	MINIMUM WELD SPACING (see par. 107 and note 5 below)	DIAMETER FUSED ZONE (see par. 108)	MINIMUM TENSION-SHEAR STRENGTH (see par. 109)
	D, IN. MIN.	R, IN.	d, IN. MAX.								
INCHES				LB	HEAT CYCLES	COOL CYCLES	PULSES	IN.	IN.	IN.	LB
0.018	1/2	3	3/16	400	6	1	2	3/8	3/8	0.17	400
0.030	1/2	5	1/4	800	6	1	2	7/16	5/8	0.18	900
0.043	1/2	5	1/4	1,600	8	1	2	1/2	3/4	0.26	1,750
0.062	5/8	7	5/16	2,200	10	1	2	5/8	1-1/8	0.32	2,050
0.093	7/8	9	7/16	3,800	9	1	4	3/4	1-1/4	0.40	5,400
0.125	7/8	12	1/2	5,000	10	1*	6	7/8	1-5/8	0.48	7,000

* Commonly known as Monel

Notes:

1. Material should be free from scale, oxides, paint, grease and oil.
2. Welding conditions determined by thickness of thinnest outside piece.
3. Data for total thickness of pile-up not exceeding 4 "T". Maximum ratio between thicknesses 3 to 1.
4. Electrode Material RWMA Class 1
Minimum Conductivity
Maximum Hardness
80% I.A.C.S.
65 Rockwell B (for forgings)
5. Minimum weld spacing is that spacing for two pieces for which no special precautions need be taken to compensate for shunted effect of adjacent welds.
6. Electrode contact surfaces must be clean to prevent surface pick-up.
7. Weld time based on 10 cycle machine. For 5 cycle machine adjust accordingly to establish total equivalent on time with minimum of cool time.

Spot and Seam Welding

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Three-Phase Frequency-Converter Machines

INTERMITTENT DRIVE		WELD SPEED APPROX. (see par. 104)	WELDS PER INCH (see par. 104)	WELD CURRENT APPROX. (see par. 105)	POST HEAT CURRENT APPROX. (see par. 105)	WIDTH FUSED ZONE (see par. 108)	MINIMUM CONTACTING OVERLAP (see par. 106)	MATERIAL THICKNESS (see par. 101 and notes 1, 2 & 3 below)
FORGE TIME	MOTOR ON TIME							
CYCLES (60/SEC)	CYCLES (60/SEC)	IN. PER MINUTE		AMP	AMP	IN.	IN.	INCHES
5	15	5.7	17	4,500	2,000	0.16	3/8	0.018
5	15	6.0	16	6,200	3,100	0.18	7/16	0.025
5	15	6.5	15	8,500	4,200	0.21	1/2	0.031
5	15	6.5	14	11,000	5,700	0.24	1/2	0.043
5	15	5.6	12	14,000	6,800	0.28	5/8	0.062
10	15	3.7	12	21,000	10,500	0.30	7/8	0.93
10	15	3.7	10	25,500	12,600	0.32	7/8	0.125

ishing 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).

7. Electrode contact surfaces must be clean to prevent surface pick-up.
8. Weld time based on 20 cycle machine. For machines with limited on time, heat and cool times should be adjusted accordingly.

Table 1.12—Spot Welding Annealed Ni-Cr-Fe† on Single-Phase Equipment

MATERIAL THICKNESS (SEE PAR. 101 AND NOTE 1 BELOW)	ELECTRODE DIAMETER (SEE PAR. 102 AND NOTES 2 AND 3 BELOW)		NET ELECTRODE FORCE (SEE PAR. 103)	WELD TIME (SEE PAR. 104)	WELDING CURRENT (APPROX.) (SEE PAR. 105)	MINIMUM CONTACTING OVERLAP (SEE PAR. 106)	MINIMUM WELD SPACING (SEE PAR. 107 AND NOTE 4 BELOW)	DIAMETER FUSED ZONE (SEE PAR. 108)	MINIMUM SHEAR STRENGTH (SEE PAR. 109)	MATERIAL THICKNESS (SEE PAR. 101 AND NOTE 1 BELOW)
	INCHES	d, IN. MAX. MIN.								
0.005 TO 1										0.005 TO 1
0.005	5/32	5/32	300	2	7,000	1/4	1/4	0.11	70	0.005
0.010	5/32	3/16	300	4	5,300	1/4	1/4	0.12	100	0.010
0.015	5/32*	3/16	300	4	5,500	1/4	1/4	0.12	105	0.015
0.021	5/32*	3/16	300	6	4,800	1/4	5/16	0.13	110	0.021
0.031	5/32*	3/16	325	6	5,400	1/4	5/16	0.13	120	0.031
0.062	5/32*	5/8	325	6	5,600	1/4	3/8	0.15	135	0.062
0.094	5/32*	5/8	325	6	5,800	1/4	3/8	0.16	145	0.094
0.125	5/32*	5/8	325	6	5,600	1/4	3/8	0.15	150	0.125
0.010 TO 1										0.010 TO 1
0.010	3/16	3/16	320	4	7,500	1/4	1/4	0.12	175	0.010
0.015	5/32*	3/16	320	4	5,500	1/4	1/4	0.13	215	0.015
0.021	5/32*	3/16	320	6	5,100	1/4	9/32	0.13	215	0.021
0.031	5/32*	3/16	350	6	5,600	1/4	9/32	0.14	290	0.031
0.063	5/32*	3/16	400	6	5,500	1/4	5/16	0.14	315	0.063
0.094	5/32*	5/8	400	6	5,800	1/4	3/8	0.15	350	0.094
0.125	5/32*	5/8	400	6	4,600	1/4	3/8	0.14	370	0.125
0.015 TO 1										0.015 TO 1
0.015	3/16	3/16	360	6	7,600	1/4	1/4	0.12	295	0.015
0.021	3/16	3/16	360	6	5,400	1/4	1/4	0.12	290	0.021
0.031	5/32*	3/16	400	8	4,600	1/4	9/32	0.13	370	0.031
0.063	5/32*	5/16	400	8	4,700	1/4	5/16	0.13	440	0.063
0.094	3/16*	5/8	400	10	4,700	1/4	11/32	0.16	535	0.094
0.125	3/16	5/8	400	12	4,600	1/4	3/8	0.16	560	0.125
0.021 TO 1										0.021 TO 1
0.021	5/32	5/32	300	12	4,000	5/16	7/16	0.12	545	0.021
0.031	5/32	3/16	350	12	4,100	5/16	7/16	0.12	535	0.031
0.063	3/16*	5/16	400	12	5,300	5/16	15/32	0.12	580	0.063
0.094	3/16*	5/8	500	12	5,900	5/16	1/2	0.15	670	0.094
0.125	3/16*	5/8	550	12	6,300	5/16	1/2	0.15	690	0.125
0.031 TO 1										0.031 TO 1
0.031	3/16	3/16	700	12	6,700	3/8	9/16	0.18	920	0.031
0.063	3/16	5/16	700	12	7,100	3/8	5/8	0.18	965	0.063
0.094	1/4*	5/8	700	12	8,300	3/8	11/16	0.20	1250	0.094
0.125	1/4*	5/8	750	12	8,500	3/8	3/4	0.20	1210	0.125
0.063 TO 1										0.063 TO 1
0.063	5/16	5/16	2070	12	12,000	5/8	1-1/8	0.31	2750	0.063
0.093	5/16	5/8	2450	16	12,000	5/8	1-3/16	0.31	2750	0.093
0.125	5/16	5/8	2600	20	12,000	5/8	1-1/4	0.32	3880	0.125
0.093 TO 1										0.093 TO 1
0.093	3/8	3/8	3870	20	15,000	3/4	1-3/16	0.37	4400	0.093
0.125	7/16	7/16	5100	30	20,000	3/4	1-1/4	0.40	4700	0.125
0.125 TO 1										0.125 TO 1
0.125	7/16	7/16	5270	30	20,100	7/8	1-5/16	0.44	6400	0.125

* INDICATES MOLYBDENUM TIPPED ELECTRODE.

NOTES:

- MATERIAL SHOULD BE FREE FROM SCALE, OXIDES, PAINT, GREASE AND OIL.
- ELECTRODE SHAPE MAY BE FLAT RATHER THAN DOMED, IN WHICH CASE THE SHEAR STRENGTHS AND NUGGET DIAMETER WILL BE HIGHER AND LARGER THAN SHOWN IN THE TABLE.
- ELECTRODE MATERIALS, CLASS 1 OR CLASS 2 OR MOLYBDENUM FACED
MINIMUM CONDUCTIVITY 80% Cu 75% Cu 33% Cu
MINIMUM HARDNESS 68 Rb 75 Rb 83 Rb
- MINIMUM WELD SPACING IS THAT SPACING FOR TWO PIECES WHEN NO SPECIAL PRECAUTIONS NEED BE TAKEN TO COMPENSATE FOR SHUNTED CURRENT EFFECT OF ADJACENT WELDS.
FOR THREE PIECES INCREASE SPACING 30 PERCENT.

* INDICATES MOLYBDENUM TIPPED ELECTRODE.

NOTES:

1. MATERIAL SHOULD BE FREE FROM SCALE, OXIDES, PAINT, GREASE AND OIL.
2. ELECTRODE SHAPE MAY BE FLAT RATHER THAN DOMED, IN WHICH CASE THE SHEAR STRENGTHS AND NUGGET DIAMETER WILL BE HIGHER AND LARGER THAN SHOWN IN THE TABLE.
3. ELECTRODE MATERIALS, CLASS 1 OR CLASS 2 OR MOLYBDENUM FACED
 MINIMUM CONDUCTIVITY 80% Cu 75% Cu 33% Cu
 MINIMUM HARDNESS 68 Rb 75 Rb 83 Rb
4. MINIMUM WELD SPACING IS THAT SPACING FOR TWO PIECES FOR WHICH NO SPECIAL PRECAUTIONS NEED BE TAKEN TO COMPENSATE FOR SHUNTED CURRENT EFFECT OF ADJACENT WELDS.
 FOR THREE PIECES INCREASE SPACING 30 PERCENT.

†COMMONLY KNOWN AS INCONEL

Spot and Seam Welding

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Table 1.13—Spot Welding Annealed Ni-Cr-Fe-Ti* on Single-Phase Equipment

MATERIAL THICKNESS (see par. 101 and notes 1, 2 & 3 below)	ELECTRODE DIAMETER AND SHAPE (see par. 102 and note 4 below)		NET ELECTRODE FORCE (see par. 103)	WELD TIME (see par. 104)	WELDING CURRENT APPROX. (see par. 105)	MINIMUM CONTACTING OVERLAP (see par. 106)	MINIMUM WELD SPACING (see par. 107 and note 5 below)	DIAMETER OF FUSED ZONE (see par. 108)	MINIMUM TENSION-SHEAR STRENGTH (see par. 109)		MINIMUM CROSS TENSION STRENGTH (see par. 109)
INCHES	D, IN. MIN	d, IN. MAX	R, IN.					IN. APPROX.	AS WELDED	AGED 4 HOURS AT 1300 F	LB
0.010	1/2	5/32	6			1/4	1/4	0.11	255	370	210
0.015	1/2	5/32	6	2	7,300	1/4	1/4	0.11	410	560	295
0.021	1/2	3/16	6	4	7,400	3/8	7/16	0.14	530	720	410
0.031	5/8	7/32	6	6	7,500	7/16	3/4	0.17	1,200	1,440	800
0.062	7/8	5/16	10	8	9,900	5/8	1-1/8	0.29	3,450	4,500	2,700
0.062	7/8	5/16	10	14	16,350	5/8	1-1/8	0.29	3,450	4,500	2,700

* Commonly known as Inconel "X"

Notes:

1. Material should be free from scale, oxides, paint, grease and oil.
2. Welding conditions determined by thickness of thinnest outside piece being welded.
3. Data for total thickness of pile-up not exceeding 4 "in". Maximum ratio between thicknesses 3 to 1.
4. Electrode Material RWMA Class 2 or Class 3
Minimum Conductivity 75% I.A.C.S.
Minimum Hardness 75 Rockwell B
90 Rockwell B
5. Minimum weld spacing is that spacing for two pieces for which no special precautions need be taken to compensate for shunted current effect of adjacent welds.

Table 1.14—Seam Welding Annealed Ni-Cr-Fe-Ti* on Single-Phase Equipment

THICKNESS OF THINTEST OUTSIDE PIECE (see par. 101 and notes 1, 2 & 3 below)	ELECTRODE WIDTH AND SHAPE (see par. 102 and note 4 below)	NET ELECTRODE FORCE (see par. 103)	ON TIME (see par. 104)	OFF TIME (pressure tight) (see par. 104)	WELD SPEED (see par. 104)	WELDS PER INCH (see par. 104)	WELDING CURRENT APPROX. (see par. 105)	MINIMUM CONTACTING OVERLAP (see par. 106)
INCHES	W, IN. MIN	E, IN. MAX	R, IN.	LB	CYCLES (60 PER SEC)	CYCLES (60 PER SEC)	IN. PER MINUTE	AMP
0.010	1/4	1/8	3	400	1	3	45	20
0.015	1/4	1/8	3	700	2	4	36	17
0.021	3/8	5/32	3	1,400	3	6	30	14
0.031	3/8	3/16	3	2,300	4	8	30	10
0.062	1/2	3/16	6	4,000	8	16	12	12
								10,300

* Commonly known as Inconel "X"

Notes:

1. Material should be free from scale, oxides, paint, grease and oil.
2. Welding conditions determined by thickness of thinnest outside piece "t".
3. Data for total thickness of pile-up not exceeding 4 "t". Maximum ratio between thicknesses 3 to 1.
4. Electrode Material RWMA
Minimum Conductivity
Minimum Hardness
** Preferred for 0.010, 0.015 and 0.021 thicknesses; for 0.031 and 0.062 Class 2 or 3 is suitable.

Class 2** or Class 3
75% I.A.C.S. or 45% I.A.C.S.
75 Rockwell B or 90 Rockwell B

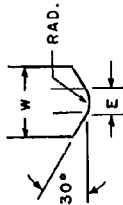
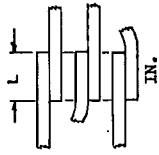


Table 1.15—Spot Welding Annealed Ni-Cr-Fe-Ti* on Three-Phase Frequency-Converter Machines

MATERIAL THICKNESS (see par. 101 and notes 1, 2 & 3 below)	ELECTRODE DIAMETER AND SHAPE (see par. 102 and note 4 below)		NET ELECTRODE FORCE (see par. 103)	WELD TIME (see par. 104 and note 6 below)		WELDING CURRENT APPROX. (see par. 105)	MINIMUM CONTACT OVERLAP (see par. 106)	MINIMUM WELD SPACING (see par. 107 and note 5 below)	DIAMETER FUSED ZONE (see par. 108)	MINIMUM TENSION-SHEAR STRENGTH (see par. 109)
INCHES	D, IN. MIN.	RAD, IN.	d, IN. MAX.	HEAT CYCLES	COOL CYCLES	PULSES (60 PER SEC)	IN.	IN.	IN.	LB
0.025	1/2	3	7/32	8	1	1	3/8	5/8	0.16	900
0.031	5/8	5	1/8	9	1	1	7/16	3/4	0.18	1,150
0.043	5/8	5	1/4	5	1	4	1/2	1	0.20	1,800
0.062	7/8	8	5/16	8	1	4	5/8	1-1/4	0.25	3,300
0.093	7/8	8	7/16	8	1	6	3/4	1-1/2	0.37	5,700

* Commonly known as Inconel "X"

Notes:

1. Material should be free from scale, oxides, paint, grease and oil.
2. Welding conditions determined by thickness of thinnest outside piece.
3. Date for total thickness of pile-up not exceed 4". Maximum ratio between thicknesses 3 to 1.
4. Electrode Material RMA Class 3 or Class 2
45% I.A.C.S.
90 Rockwell B
75% I.A.C.S.
75 Rockwell B
5. Minimum weld spacing is that spacing for two pieces for which no special precautions need be taken to compensate for shunted current effect of adjacent welds.
6. 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 1.16—Seam Welding Annealed Ni-Cr-Fe-Ti* on

MATERIAL THICKNESS (see par. 101 and notes 1, 2 & 3 below)	ELECTRODE WIDTH AND SHAPE (see par. 102 and note 4 below)			ELECTRODE FORCE (see par. 103)	DRIVE			
					INTERMITTENT (SEE NOTE 5)			
					WELD TIME (see par. 104 and note 6)	COOL TIME or INTER-PULSE TIME (see par. 104)	PULSES	FORGE TIME
INCHES	E, IN. MAX	W, IN. MIN	R, IN.	LB	CYCLES (60/SEC)	CYCLES (60/SEC)		CYCLES (60/SEC)
0.025	7/32	3/8	3	1,200	10	1	—	—
0.031	1/4	3/8	5	1,300	12	2	—	—
0.043	1/4	1/2	5	1,700	14	5	—	—
0.062	5/16	1/2	8	2,500	20	1	1	15
0.093	7/16	3/4	10	3,500	15	1	2	15
0.125	1/2	3/4	10	4,500	20	1	2	20

* Commonly known as Inconel "X"

Notes:

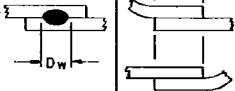
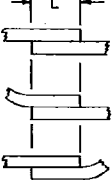
1. Material should be free from scale, oxides, paint, grease and oil.
2. Welding condition determined by thickness of thinnest outside piece "T".
3. Data for total thickness of pile-up not exceeding 4 "T". Maximum ratio between thicknesses 3 to 1.

- | | | | |
|----------------------------|----------------|----|----------------|
| 4. Electrode Material RWMA | <u>Class 3</u> | or | <u>Class 2</u> |
| Minimum Conductivity | 45% I.A.C.S | | 75% I.A.C.S. |
| Maximum Hardness | 90 Rockwell B | | 75 Rockwell B |

Spot and Seam Welding

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Three-Phase Frequency-Converter Machines

DRIVE		WELD SPEED APPROX.	WELDS PER INCH	WELD CURRENT APPROX.	WIDTH FUSED ZONE APPROX.	MINIMUM CONTACTING OVERLAP	MATERIAL THICKNESS
INTERM. MOTOR ON TIME	CONTINUOUS	(see par. 104)	(see par. 104)	(see par. 105)	(see par. 108)	(see par. 106)	(see par. 101 and notes 1, 2 & 3 below)
							
CYCLES (60/SEC)		IN. PER MINUTE		AMP	IN.	IN.	INCHES
—	X	17	20	6,000	0.17	3/8	0.025
—	X	15	18	6,500	0.22	7/16	0.031
—	X	13	15	7,000	0.24	1/2	0.043
15	—	6	12	8,500	0.27	5/8	0.062
15	—	5.5	11	11,000	0.36	3/4	0.093
15	—	4.5	11	13,000	0.42	7/8	0.125

5. Intermittent motion recommended for thicknesses greater than .050 in. to .050 in. to produce defect-free welds.

6. Weld time based on 20 cycle machine. For machines with limited on time, heat and cool times should be adjusted accordingly.

Table 1.17—Spot Welding Annealed Ni-Cr-Fe-Ti* on Three-Phase Dry-Disc Rectifier Machines

MATERIAL THICKNESS (see notes 1, 2, & 3 below)	ELECTRODE DIAMETER AND SHAPE (see par. 102 and note 4 below)	NET ELECTRODE FORCE (see par. 103)		FORGE DELAY TIME (see note 6 below)	WELD TIME (see par. 104)	QUENCH TIME (see par. 104)	TEMPER TIME (see par. 104)	WELDING CURRENT APPROX.		MINIMUM CONTACTING OVERLAP (see par. 106)	MINIMUM WELD SPACING (see par. 107 and note 5 below)	DIAMETER OF FUSED ZONE (see par. 108)	AVERAGE TENSION-SHEAR STRENGTH (see par. 108)
		WELD	FORGE					WELD	TEMPER				
INCHES	D, IN. MIN	R, IN.	LB	LB	CYCLES (60/SEC)	CYCLES (60/SEC)	CYCLES (60/SEC)	AMP	AMP	IN.	CENTER TO CENTER IN.	IN.	LB
0.032	5/8	6	1,700	2,800	17	13	13	6,500	4,400	7/16	3/4	0.160	1,200
0.062	7/8	8	2,600	4,500	43	35	46	8,300	5,650	5/8	1-1/4	0.270	3,600
0.093	7/8	8	3,500	6,200	69	55	73	10,000	7,000	3/4	1-1/2	0.327	6,000
0.125	7/8	8	4,300	7,700	91	73	99	11,750	8,350	7/8	2-1/8	0.379	8,140
0.143	1-1/4	8	4,650	8,400	104	83	112	12,700	9,050	1	2-3/8	0.385	9,200
0.156	1-1/4	8	4,950	8,800	113	89	121	13,600	9,700	1-1/4	2-3/4	0.423	10,100
0.188	1-1/2	8	5,600	9,500	128	100	145	14,700	10,450	1-3/8	3	0.456	11,300

*Commonly known as Inconel "X"

NOTES:

1. Material free of scale, degreased, and pickled in a solution of 10 parts water, 10 parts conc. nitric acid and 1.5 parts hydrofluoric acid, for 20 to 30 minutes at 75 degrees F.
2. Welding conditions determined by thickness of thinnest outside piece being welded.
3. Data for total thickness of pile-up not exceeding 4 "in". Maximum ratio between thicknesses 3 to 1.
4. Electrode material RMA Class 2 or Class 3
Minimum conductivity 75% I.A.C.S.
Minimum hardness 75 Rockwell B
45% I.A.C.S.
90 Rockwell B
5. Minimum weld spacing is that spacing for two pieces for which no special precautions need be taken to compensate for shunted current effect of adjacent welds.
6. The time from beginning of weld time to the instant of application of forging force.

Table 1.18—Roll-Spot Seam Welding Annealed Ni-Cr-Fe-Ti* on Three-Phase Dry-Disc Rectifier Machines

MATERIAL THICKNESS (see par. 101 and notes 1, 2 and 3 below)	WHEEL WIDTH AND SHAPE (see par. 102 and notes 4, 5 and 6 below)	NET ELECTRODE FORCE (see par. 103)		INTERMITTENT DRIVE (see par. 104)				WELDING CURRENT APPROX. (see par. 105)		SPOTS PER INCH	WELD SPEED (see note 8 below)	FUSED ZONE WIDTH (see par. 108)	MINIMUM CONTACTING OVERLAP (see par. 106)
		WELD FORCE	FORGE	FORCE-DELAY TIME (see note 7 below)	WELD TIME	QUENCH TIME	TEMPER TIME	WELD	TEMPER				
INCHES	W, IN. MIN	R, IN.	LB	LB	CYCLES (60/SEC)	CYCLES (60/SEC)	CYCLES (60/SEC)	CYCLES (60/SEC)	AMP	AMP	IN. PER MINUTE	IN.	IN.
0.032	3/8	3	1,700	2,800	17	13	0	13	5,150	4,200	12.0	5.0	7/16
0.062	1/2	6	2,600	4,500	43	35	3	45	5,350	5,070	10.0	3.0	5/8
0.093	3/4	8	3,500	6,200	69	55	7	73	10,000	5,200	9.0	2.4	3/4
0.125	3/4	8	4,300	7,700	91	73	13	98	11,750	5,350	8.5	2.1	3/4
0.143	3/4	10	4,650	8,300	103	82	17	112	12,500	9,000	8.0	1.8	7/8
0.156	3/4	10	4,900	8,750	110	86	21	120	13,200	9,250	7.5	1.7	1.0
0.188	3/4	10	5,600	9,500	128	100	30	187	14,750	10,300	6.0	1.5	1.0

commonly known as Inconel "X"

NOTES:

- Material free of scale, degressed and pickled in a solution of 10 parts water, 10 parts conc. nitric acid and 1.5 parts hydrofluoric acid for 20 to 30 min at 75 F.
- Welding conditions determined by thickness of thinnest outside piece.
- Data for total thickness of pile-up not exceeding 4 "t". Maximum ratio between thicknesses 3 to 1.
- Electrode material RWMA Class 2 or Class 3
Minimum conductivity 75% I.A.C.S.
Minimum hardness 75 Rockwell B 90 Rockwell B

Where practical, both wheels should be of same diameter and radius. When geometry of parts makes it possible 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.

- When the seam closes upon itself as in a circular container, it is advisable to have a reduced current level on this closing spot.
- The time from beginning of weld time to the instant of application of forging force.
- Based on using 20 cycles hold time and 15 cycles index time with the given spots per inch.

*Commonly known as inconel "X"

NOTES:

- Material free of scale, degreased and pickled in a solution of 10 parts water, 10 parts conc. nitric acid and 1.5 parts hydrofluoric acid for 20 to 30 min at 75 F.
- Welding conditions determined by thickness of thinnest outside piece.
- Data for total thickness of pile-up not exceeding 4 "r". Maximum ratio between thicknesses 3 to 1.
- Electrode material RWMA Class 2 or Class 3
Minimum conductivity 75% I.A.C.S. 45% I.A.C.S.
Minimum hardness 75 Rockwell B 90 Rockwell B
- Where practical, both wheels should be of same diameter and radius. When geometry of parts makes it possible 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.
- When the seam closes upon itself as in a circular container, it is advisable to have a reduced current level on this closing spot.
- The time from beginning of weld time to the instant of application of forging force.
- Based on using 20 cycles hold time and 15 cycles index time with the given spots per inch.

Table 1.19—Spot Welding Annealed Nickel on Single-Phase Equipment

MATERIAL THICKNESS (SEE PAR. 101 AND NOTE 1 BELOW)	ELECTRODE DIAMETER (SEE PAR. 102 AND NOTES 2 AND 3 BELOW)		NET ELECTRODE FORCE (SEE PAR. 103)	WELD TIME (SEE PAR. 104)	WELDING CURRENT (APPROX.) (SEE PAR. 105)	MINIMUM CONTACTING OVERLAP (SEE PAR. 106)	MINIMUM WELD SPACING (SEE PAR. 107 AND NOTE 4 BELOW)	DIAMETER FUSED ZONE (SEE PAR. 108)	MINIMUM SHEAR STRENGTH (SEE PAR. 109)	MATERIAL THICKNESS (SEE PAR. 101 AND NOTE 1 BELOW)
	d, IN., MAX.	D, IN., MIN.								
INCHES			LBS.	CYCLES (60 PER SEC.)	AMPS.	IN.	IN.	IN.	LBS.	INCHES
0.005 TO:										0.005 TO:
0.005	5/32	5/32	100	3	7,100	1/4	3/8	0.10	30	0.005
0.010	5/32	5/32	100	3	7,400	1/4	7/16	0.10	35	0.010
0.015	5/32	5/32	110	3	7,500	1/4	7/16	0.10	40	0.015
0.021	5/32	5/32	110	3	7,800	1/4	1/2	0.10	45	0.021
0.031	5/32	3/16	110	3	8,000	1/4	1/2	0.10	50	0.031
0.063	5/32	3/16	115	3	8,100	1/4	5/8	0.10	50	0.063
0.093	5/32	3/16	115	3	8,150	1/4	5/8	0.10	50	0.093
0.125	5/32	3/16	115	3	8,200	1/4	5/8	0.10	55	0.125
0.010 TO:										0.010 TO:
0.010	3/16	3/16	130	3	11,800	1/4	3/8	0.12	135	0.010
0.015	5/32	3/16	130	3	11,900	1/4	3/8	0.12	145	0.015
0.021	5/32	3/16	130	3	12,000	1/4	7/16	0.12	150	0.021
0.031	5/32	3/16	130	3	12,200	1/4	7/16	0.12	160	0.031
0.063	5/32	3/16	140	3	12,300	1/4	1/2	0.12	185	0.063
0.094	5/32	3/16	140	3	12,300	1/4	5/8	0.12	190	0.094
0.125	5/32	3/16	150	3	12,500	1/4	5/8	0.12	210	0.125
0.015 TO:										0.015 TO:
0.015	3/16	3/16	250	3	12,300	1/4	7/16	0.12	180	0.015
0.021	3/16	3/16	250	3	12,500	1/4	1/2	0.13	250	0.021
0.031	3/16	3/16	250	3	12,600	1/4	1/2	0.13	280	0.031
0.063	3/16	1/4	260	3	12,800	1/4	9/16	0.13	300	0.063
0.094	3/16	5/8	260	3	13,000	1/4	5/8	0.13	305	0.094
0.125	3/16	5/8	260	3	13,100	1/4	5/8	0.13	310	0.125
0.021 TO:										0.021 TO:
0.021	5/32	5/32	370	4	7,800	5/16	9/16	0.12	350	0.021
0.031	5/32	5/32	370	4	8,200	5/16	5/8	0.12	370	0.031
0.063	5/32	5/32	370	4	8,600	5/16	5/8	0.12	395	0.063
0.094	5/32	5/8	380	4	8,800	5/16	11/16	0.12	430	0.094
0.125	5/32	5/8	380	4	9,000	5/16	3/4	0.13	450	0.125
0.031 TO:										0.031 TO:
0.031	3/16	3/16	900	4	15,400	3/8	7/8	0.18	780	0.031
0.063	3/16	3/16	900	4	15,200	3/8	7/8	0.17	770	0.063
0.094	3/16	3/16	900	6	13,500	3/8	1	0.18	840	0.094
0.125	3/16	5/8	980	6	14,200	3/8	1	0.18	930	0.125
0.063 TO:										0.063 TO:
0.063	1/4	1/4	1720	6	21,600	5/8	1-1/2	0.25	2400	0.063
0.094	1/4	1/4	1800	8	20,000	5/8	1-5/8	0.25	2550	0.094
0.125	1/4	1/4	1800	10	21,000	5/8	1-3/4	0.25	2650	0.125
0.094 TO:										0.094 TO:
0.094	5/16	5/16	2300	12	26,400	3/4	1-7/8	0.31	3600	0.094
0.125	5/16	5/16	2300	20	25,400	3/4	2	0.31	3780	0.125
0.125 TO:										0.125 TO:
0.125	3/8	3/8	3300	20	31,000	7/8	2-1/4	0.37	5600	0.125

NOTES:

- MATERIAL SHOULD BE FREE FROM SCALE, OXIDES, PAINT, GREASE AND OIL.
- 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.
- ELECTRODE MATERIALS, **CLASS I** OR **CLASS E**
 MINIMUM CONDUCTIVITY 80% Cu 75% Cu
 MINIMUM HARDNESS 68 Rb 75 Rb
- MINIMUM WELD SPACING IS THAT SPACING FOR TWO PIECES FOR WHICH NO SPECIAL PRECAUTIONS NEED BE TAKEN TO COMPENSATE FOR SHUNTED CURRENT EFFECT OF ADJACENT WELDS.
 FOR THREE PIECES INCREASE SPACING 30 PERCENT.

II. RECOMMENDED PRACTICE FOR PROJECTION WELDING

Low-Carbon and Stainless Steels

NOTE: The data are presented in three parts: Design Data (Table 2.1), Manufacturing Process Data (Tables 2.2 and 2.3), and Punch and Die Design Data (Table 2.4). The values specified are for single projection welds. For modifications to be made for multiple projections see Paragraph 210 below.

The correlation of these data with tests conducted have definitely shown that consistent tension-shear values cannot be obtained until a weld of diameter, penetration and soundness equivalent to a spot weld in the same thickness of material is obtained. In other words, a projection weld becomes a spot weld, and is only a convenient means of making spot welds with the advantages of smaller overlap, less maintenance of electrodes, etc., and the production of multiple welds.

Work on these data is being continued and will include investigation of other materials; the possible use of lower electrode forces and welding currents for both single and multiple welds; the use of a smaller number of projections for different material thicknesses; and the possible increase in the specified tolerances for projection diameters and heights.

201. MATERIAL

These *Recommended Practices* are applicable to SAE 1010 Steel, and to stainless steel of types 309, 310, 316, 317, 321, 347 and 349 which are non-hardenable* and which contain a maximum of 0.15% carbon in the thickness ranges shown in the tables.

202. ELECTRODE DIAMETER AND SHAPE

Only the flat-face type of electrode having sides beveled to a 20° angle is specified. Small diameter, d , as specified is a minimum and is equal to at least twice the diameter of the projection. The values shown may be increased within reason, without appreciable effect. The larger electrode diameter is relatively unimportant as long as a flat electrode face and proper water cooling of the electrode are maintained. The matter of water cooling is especially important.

Whether copper-base alloy electrodes (RWMA Group A) or copper-tungsten alloy electrodes (RWMA Group B) are used depends on the

* Nonhardenable materials are those which cannot be hardened by heat treatment.

unit pressure and production requirements. Higher hardness electrodes are used for greater pressure (25,000-50,000 psi.) to avoid indentation of the electrode face.†

203. NET ELECTRODE FORCE

The values shown in the tables refer to the exact force between contact surfaces, such as would be obtained in welding test pieces. The data are based on unit electrode pressures of 15,000 psi. for low-carbon and 25,000 psi. for stainless steels on the area of the weld (area of fused zone).

204. TIME

The values shown for "Weld Time" and "Hold Time" are in cycles based on 60 per second. Sufficient "Hold Time" should be used so that the material is below visible red heat when the electrode leaves the surface.

205. MINIMUM SHEAR STRENGTH

A Tension-Shear test in a reliable testing machine with the samples unconfined is the accepted method of checking this value.* Welds made during the setting up of a machine should never be used to establish shear strength. Only those welds made after the machine has been properly adjusted should be considered in the evaluation.

In considering weld strength, it should be recognized that variations in individual weld strengths exist no matter how accurately the welding variables are controlled. Shop strength, which determines the acceptable machine setting, should therefore be above the minimum value indicated. How much above, should be determined by test and experience; as a guide, it should be set sufficiently above the values indicated (approximately 20%) so that no welds will fall below the indicated minimum values when tested.

Data have been furnished for steels in three different ranges of tensile strength: Values in the first column, "Tensile Strength Below 70,000 Psi.," are applicable to low-carbon steel (SAE 1010). Values in the second column, "Tensile Strength 70,000 up to 150,000 Psi.," are applicable to low-carbon (SAE 1010) and stainless steels which are fully annealed or one-quarter hard. Values in the third column, "Tensile Strength 150,000 Psi. and Above," are applicable to one-half and up to full-hard stainless steels.

206. WELDING CURRENT

These values, shown in secondary amperes at the welding electrode, are approximate and are intended to help calculate and specify the capacity of

† For most of the tests of the data Class 2 (minimum conductivity—75% of copper; minimum hardness—75 Rockwell "B") and Class 12 (minimum conductivity—29% of Copper; minimum hardness—100 Rockwell "B") were used.

* See "Standard Methods for Testing Resistance Welds," page 79, for standard procedure for Tension-Shear Tests.

welding machines. They should produce welds having minimum shear strengths at least 20% above the values specified.

207. DIAMETER OF FUSED ZONE

These data are helpful when cross-sectional etch tests are made to check the size, penetration and soundness of welds. The values shown are based on photomicrographs made of specimens welded using the data in these *Recommended Practices* and checked for the above properties.

208. MINIMUM WELD SPACING

The value shown in the sketches in Table 2.1 apply to two thicknesses only, with a maximum ratio between the thicker and thinner pieces of three to one.

209. MINIMUM CONTACTING OVERLAP

These values indicate the required overlap (not including any radii from forming, etc.) as shown in the sketches in Table 2.1. They are intended for single projections only. It is extremely important to avoid using overlap below the values specified otherwise material distortion or weld expulsion may result.

210. MULTIPLE PROJECTION WELDS

Tests indicate that for multiple projections, it is only necessary to multiply the electrode force and welding current for one projection by the number of projections to obtain sound welds of maximum strength using, of course, the proper size of electrode to cover all projections. The welding time is the same as for single projection welds.

It is suggested that the electrode contact faces be machined to a minimum of twice the diameter of the projection over each projection.

The minimum spacing for multiple projection welds is normally the same as for spot welds (Table 1.1). This is necessary to obtain separate welds; closer spacing will result in one large weld.

211. PROJECTION HEIGHT AND DIAMETER

These values (Table 2.1) are the result of the correlation of data obtained from several sources and tests conducted to determine a projection which could be as large as possible without flattening under the recommended electrode forces and which would produce a reasonably sound weld having a shear strength equal to that of an equivalent spot weld in the same nominal thickness of material.

212. PUNCH AND DIE DESIGN

These data (Table 2.4) will produce the proper sizes of projection on

the material thicknesses shown. When using the values for the punch and dies shown, the die pressure should be just enough to form the projection and not distort the piece.

Table 2.1—Projection Welding Design Data

THICKNESS "T" OF THINNEST OUTSIDE PIECE (NOMINAL) (SEE PAR. 201 AND NOTES 1, 2, 3 AND 4 BELOW)			MINIMUM SHEAR STRENGTH (SINGLE PROJECTIONS ONLY) (SEE PAR. 205) LB.			DIAMETER OF FUSED ZONE MINIMUM (AT WELD INTERFACE) (SEE PAR. 207)		THICKNESS "T" OF THINNEST OUTSIDE PIECE (NOMINAL) (SEE PAR. 201 AND NOTES 1, 2, 3 AND 4 BELOW)	
INCHES	IN.	IN.	TENSILE STRENGTH BELOW 70,000 PSI	TENSILE STRENGTH 70,000 UP TO 150,000 PSI	TENSILE STRENGTH 150,000 PSI AND ABOVE	IN.	IN.	INCHES	IN.
0.010	0.055	0.015	130	180	250	0.112	1/8	0.010	
0.012	0.055	0.015	170	220	330	0.112	1/8	0.012	
0.014	0.055	0.015	200	200	380	0.112	1/8	0.014	
0.016	0.067	0.017	240	330	450	0.112	5/32	0.016	
0.021	0.067	0.017	320	440	600	0.140	5/32	0.021	
0.025	0.081	0.020	450	600	820	0.140	3/16	0.025	
0.031	0.094	0.022	635	850	1100	0.169	7/32	0.031	
0.034	0.094	0.022	790	1000	1300	0.169	7/32	0.034	
0.044	0.119	0.028	920	1300	2000	0.169	9/32	0.044	
0.050	0.119	0.028	1350	1700	2400	0.225	9/32	0.050	
0.062	0.156	0.035	1950	2250	3400	0.225	3/8	0.062	
0.070	0.156	0.035	2300	2800	4200	0.281	3/8	0.070	
0.078	0.187	0.041	2700	3200	4800	0.281	7/16	0.078	
0.094	0.218	0.048	3450	4000	6100	0.281	1/2	0.094	
0.109	0.250	0.054	4150	5000	7000	0.338	5/8	0.109	
0.125	0.281	0.060	4800	5700	8000	0.338	11/16	0.125	
0.140	0.312	0.066	6000	—	—	7/16	3/4	0.140	
0.156	0.343	0.072	7500	—	—	1/2	13/16	0.156	
0.171	0.375	0.078	8500	—	—	9/16	7/8	0.171	
0.187	0.406	0.085	10000	—	—	9/16	15/16	0.187	
0.203	0.437	0.091	12000	—	—	5/8	1	0.203	
0.250	0.531	0.110	15000	—	—	11/16	1 1/4	0.250	

NOTES:

1. TYPES OF STEEL:
LOW-CARBON - SAE 1010
STAINLESS - TYPES 309, 310, 316, 317, 321, 347 AND 349
(MAX. CARBON CONTENT 0.15%)
2. MATERIAL SHOULD BE FREE FROM SCALE, OXIDES, PAINT, GREASE AND OIL
3. SIZE OF PROJECTION NORMALLY DETERMINED BY THICKNESS OF THINNER PIECE, AND PROJECTION SHOULD BE ON THICKER PIECE WHERE POSSIBLE
4. DATA BASED ON THICKNESS OF THINNER SHEET, AND FOR TWO THICKNESSES ONLY
5. CONTACTING OVERLAP DOES NOT INCLUDE ANY RADII FROM FORMING, ETC.
6. WELD SHOULD BE LOCATED IN CENTER OF OVERLAP
7. PROJECTION SHOULD BE MADE ON PIECE OF HIGHER CONDUCTIVITY WHEN DISSIMILAR METALS ARE WELDED
8. FOR DIAMETER OF PROJECTION "D" A TOLERANCE OF ± 0.003 IN. IN MATERIAL UP TO AND INCLUDING 0.050 IN. IN THICKNESS AND ± 0.007 IN. IN MATERIAL OVER 0.050 IN. IN THICKNESS MAY BE ALLOWED
9. FOR HEIGHT OF PROJECTION "H" A TOLERANCE OF ± 0.002 IN. IN MATERIAL UP TO AND INCLUDING 0.050 IN. IN THICKNESS AND ± 0.005 IN. IN MATERIAL OVER 0.050 IN. IN THICKNESS MAY BE ALLOWED
10. SEE TABLE 2.4 FOR DATA ON PUNCH AND DIE DESIGNS FOR MAKING PROJECTIONS

Projection Welding

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Table 2.2—Manufacturing Process Data for Low-Carbon Steel

THICKNESS "T" OF THINNEST OUTSIDE PIECE (NOMINAL) (SEE PAR. 201 AND NOTES 1, 2 AND 3 BELOW)	ELECTRODE FACE DIAMETER "d" ($d = 2 \times \text{PROJ. DIA.}$) (SEE PAR. 202 AND NOTE 5 BELOW)		NET ELECTRODE FORCE (SEE PAR. 203)	WELD TIME (SEE PAR. 204)		HOLD TIME (SEE PAR. 204)	WELDING CURRENT (AT ELECTRODES) 60 CYCLES A.C. (APPROX.) (SEE PAR. 206)	THICKNESS "T" OF THINNEST OUTSIDE PIECE (NOMINAL) (SEE PAR. 201 AND NOTES 1, 2 AND 3 BELOW)
	INCHES	IN.	LB.	CYCLES (60 PER SEC.)	CYCLES (60 PER SEC.)	CYCLES (60 PER SEC.)	AMPS	INCHES
0.014		1/8	175	7	15		5000	0.014
0.021		3/32	300	10	15		6000	0.021
0.031		3/16	400	15	15		7000	0.031
0.044		1/4	400	20	15		7000	0.044
0.062		5/16	700	25	15		9500	0.062
0.078		3/8	1200	30	30		13000	0.078
0.094		7/16	1200	30	30		14500	0.094
0.109		1/2	1700	30	45		16000	0.109
0.125		9/16	1700	30	45		17000	0.125

NOTES:

1. TYPES OF STEEL—SAE 1010 (MAX. CARBON CONTENT 0.15%)
2. MATERIAL SHOULD BE FREE FROM SCALE, OXIDES, PAINT, GREASE AND OIL
3. DATA BASED ON THICKNESS OF THINNER SHEET, AND FOR TWO THICKNESSES ONLY. MAXIMUM RATIO BETWEEN TWO THICKNESSES 3 TO 1
4. SEE TABLE 2.1 FOR STANDARD PROJECTIONS
5. ELECTRODE MATERIAL, CLASS 2
MINIMUM CONDUCTIVITY — 75% OF COPPER
MAXIMUM HARDNESS — 75 ROCKWELL "B"

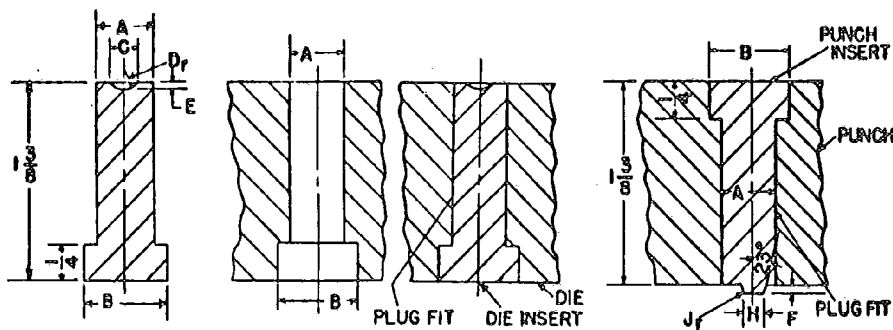
Table 2.3—Manufacturing Process Data for Stainless Steel

THICKNESS "T" OF THINNEST OUTSIDE PIECE (NOMINAL) (SEE PAR. 201 AND NOTES 1, 2 AND 3 BELOW)	ELECTRODE FACE DIAMETER d (d = 2 ± PROJ. DIA.) (SEE PAR. 202 AND NOTE 5 BELOW)	NET ELECTRODE FORCE (SEE PAR. 203)	WELD TIME (SEE PAR. 204)	HOLD TIME (SEE PAR. 204)	WELDING CURRENT (AT ELECTRODES) 60 CYCLES A.C. (APPROX.) (SEE PAR. 206)	THICKNESS "T" OF THINNEST OUTSIDE PIECE (NOMINAL) (SEE PAR. 201 AND NOTES 1, 2 AND 3 BELOW)	
						INCHES	INCHES
0.014	1/8	300	7	15	4500	0.014	0.014
0.021	3/32	500	10	15	4750	0.021	0.021
0.031	3/16	700	15	15	5750	0.031	0.031
0.044	1/4	700	20	15	6000	0.044	0.044
0.062	5/16	1200	25	15	7500	0.062	0.062
0.078	3/8	1900	30	30	10000	0.078	0.078
0.084	7/16	1900	30	30	10000	0.084	0.084
0.109	1/2	2800	30	45	13000	0.109	0.109
0.125	9/16	2800	30	45	14000	0.125	0.125

NOTES:

1. TYPES OF STEEL — 309, 310, 316, 317, 321, 347 AND 349 (NON-HARDENABLE; MAX. CARBON CONTENT — 0.15 %)
2. MATERIAL SHOULD BE FREE FROM SCALE, OXIDES, PAINT, GREASE AND OIL
3. DATA BASED ON THICKNESS OF THINNER SHEET, AND FOR TWO THICKNESSES ONLY. MAXIMUM RATIO BETWEEN TWO THICKNESSES 3 TO 1
4. SEE TABLE 2.1 FOR STANDARD PROJECTIONS
5. ELECTRODE MATERIAL, CLASS 2 OR CLASS 12
MINIMUM CONDUCTIVITY — 75
MAXIMUM HARDNESS — 75
29% OF COPPER
100 ROCKWELL "B"

Table 2.4—Punch and Die Design Data



MAT THICKNESS	PT. NO.	A	B	± 0.02 C	D_r	± 0.01 E	± 0.01 F	± 0.01 H	J_r
.012 TO .016	1	3/8	9/16	.055	.033	.015	.015	.035	.005
.016 TO .020	2	3/8	9/16	.067	.042	.017	.020	.039	.005
.025	3	3/8	9/16	.081	.050	.020	.025	.044	.005
.031	4	3/8	9/16	.094	.062	.022	.030	.050	.005
.035	5	3/8	9/16	.094	.062	.022	.030	.050	.005
.044	6	3/8	9/16	.119	.078	.028	.035	.062	.005
.050	7	3/8	9/16	.119	.078	.028	.035	.062	.005
.062	8	3/8	9/16	.156	.105	.035	.043	.081	.005
.071	9	3/8	9/16	.156	.105	.035	.043	.081	.005
.078	10	3/8	9/16	.187	.128	.041	.055	.104	.010
.094	11	1/2	1 1/16	.218	.148	.048	.065	.115	.010
.109	12	1/2	1 1/16	.250	.172	.054	.075	.137	1/64
.125	13	1/2	1 1/16	.281	.193	.060	.085	.154	1/64
.140	14	1/2	1 1/16	.312	.217	.066	.096	.172	1/64
.156	15	5/8	1 3/16	.343	.243	.072	.107	.191	1/64
.171	16	5/8	1 3/16	.375	.265	.078	.118	.210	1/64
.187	17	5/8	1 3/16	.406	.285	.085	.130	.229	1/64
.203	18	1 1/16	7/8	.437	.308	.091	.143	.240	.020
.250	19	1 3/16	1	.531	.375	.110	.175	.285	.025

MATERIAL:-

MAKE DIE & PUNCH INSERTS FROM AIR-HARDENING CHROME-VANADIUM STEEL.
FINISH ALL OVER AND HARDEN TO 65-68 ROCKWELL "C" SCALE.

NOTE:

EACH PART NUMBER REPRESENTS ONE COMPLETE DIE UNIT WHICH IS MADE UP
OF PUNCH & DIE INSERT.

ALL WORKING SURFACES OF DIE UNIT MUST BE POLISHED.

III. RECOMMENDED PRACTICE FOR FLASH WELDING

Low and Medium Forging Strength Steels

301. INTRODUCTION

The data presented herewith represent a compilation of information received from members of the Subcommittee on Flash Welding, AWS Resistance Welding Committee, and have been circulated among numerous fabricators before being drafted in their present form.

302. GENERAL

These data should produce welds of the highest quality. No inference is intended that variations cannot be made from these data, but the exact degree of variation which may be made and still produce welds of optimum quality is not known.

In correlating the material for these standards, it was realized that it would be necessary first to define the process variables as well as to specify the method of measurement of some of these variables. Such definitions with accompanying definition chart are given below.

When applying these standards and considering the definitions, it should be realized that not all flash welding equipment nor all flash welding schedules simultaneously make use of all the listed variables.

The most commonly met applications use no preheating, dual flashing currents or postheating, but consist of flashing at a single current, followed by upsetting. Most equipment now in production performs only the two above functions.

303. DEFINITIONS

(See Flash Welding Definitions Chart, Fig. 3.1.)

- 3.1 — *Weld Line* is the plane of fusion of the welded parts.
- 3.2 — *Flash* is the extraneous material which is thrown and extruded from the weld line during the flashing and upsetting actions.
- 3.3 — *Initial Die Opening* (*A*, in.) is the distance between the dies when the workpieces first contact.
- 3.4 — *Material Lost* (*B*, in.) is the total length of material that is used in making the weld.
- 3.5 — *Final Die Opening* (*C*, in.) is the distance between the dies at the completion of the weld.

- 3.6 —*Total Flash-off* (D , in.) is the total length of material that is lost in flashing.
- 3.7 —*Manual Flash-off* (E , in.) is the length of material that is lost in flashing while the flashing is controlled manually.
- 3.8 —*Automatic Flash-off* (F , in.) is the length of material that is lost in flashing while the flashing is controlled automatically.
- 3.9 —*Preheating Loss* (G , in.) is the length of material that is lost as the result of the preheating action.
- 3.10 —*Total Upset* (H , in.) is the length of material that is lost as the result of the forging action.
- 3.11 —*Material X Lost* (J , in.) is the length of Material X that is used in making the weld.
- 3.12 —*Material Y Lost* (K , in.) is the length of Material Y that is used in making the weld.
- 3.13 —*Initial Extension, Material X* (L , in.) is the dimension from the die which clamps Material X to that point on Material X which first contacts Material Y.
- 3.14 —*Initial Extension Material Y* (M , in.) is the dimension from the die which clamps Material Y to that point on Material Y which first contacts Material X.
- 3.15 —*Final Extension, Material X* (N , in.) is the dimension from the die which clamps Material X to the Weld Line at the completion of the weld.
- 3.16 —*Final Extension, Material Y* (P , in.) is the dimension from the die which clamps Material Y to the Weld Line at the completion of the weld.
- 3.17 —*Travel at I_1* (Q , in.) is the dimension the movable platen (Material Y) travels during the flashing current, I_1 .
- 3.18 —*Travel at I_2* (R , in.) is the dimension the movable platen (Material Y) travels during the flashing current, I_2 .
- 3.19 —*Spring-Back* (in.) is the deflection of the welding machine when making the weld.
- 3.20 —*Preheating Time* (sec.) is the time during which preheating is taking place.
- 3.21 —*Manual Flashing Time* (sec.) is the time during which flashing by manual control is taking place.
- 3.22 —*Automatic Flashing Time* (sec.) is the time during which flashing by automatic control is taking place.
- 3.23 —*Time at Flashing Current I_1* (sec.) is the time during which flashing with current I_1 is taking place.
- 3.24 —*Time at Flashing Current I_2* (sec.) is the time during which flashing with current I_2 is taking place.

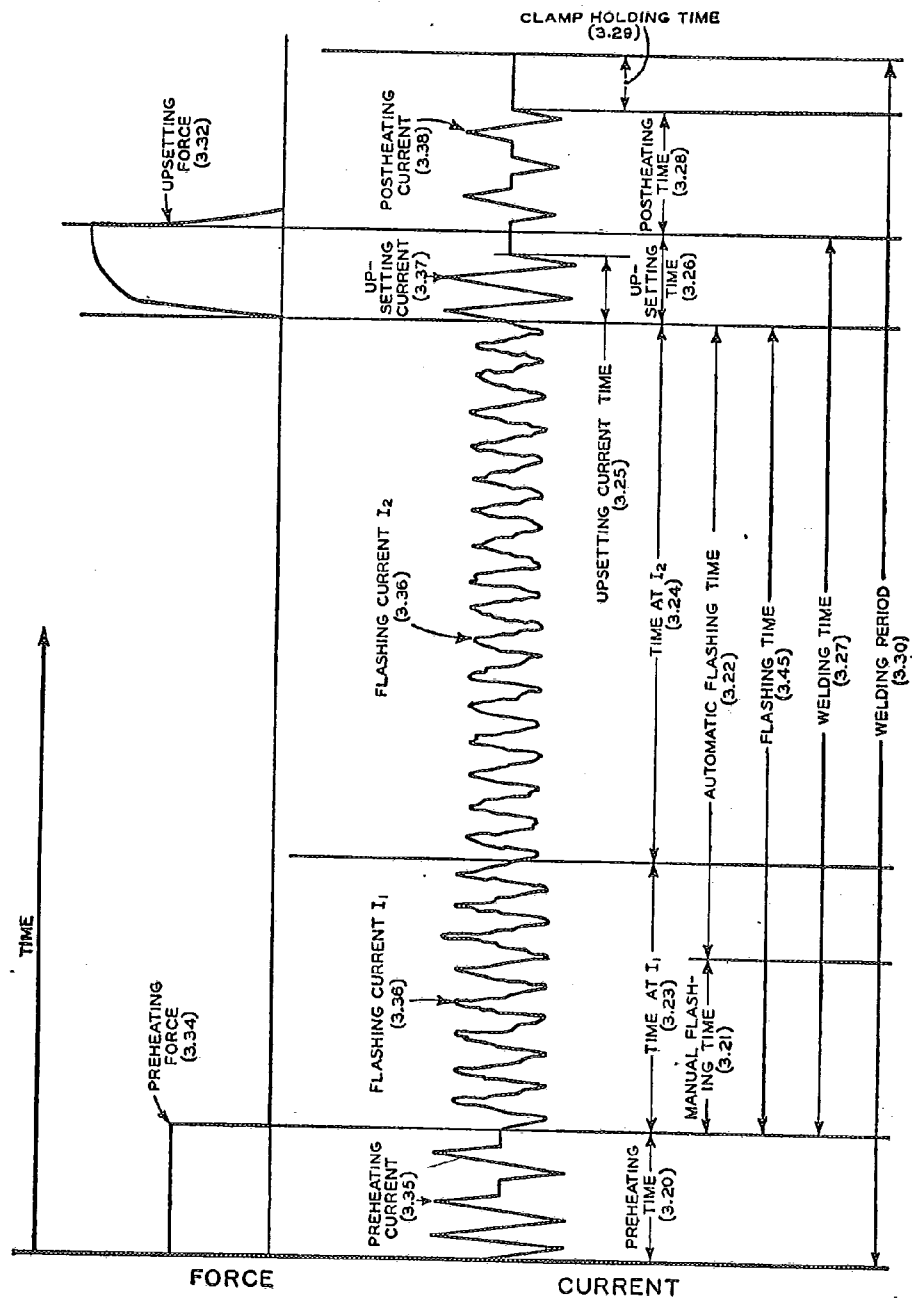
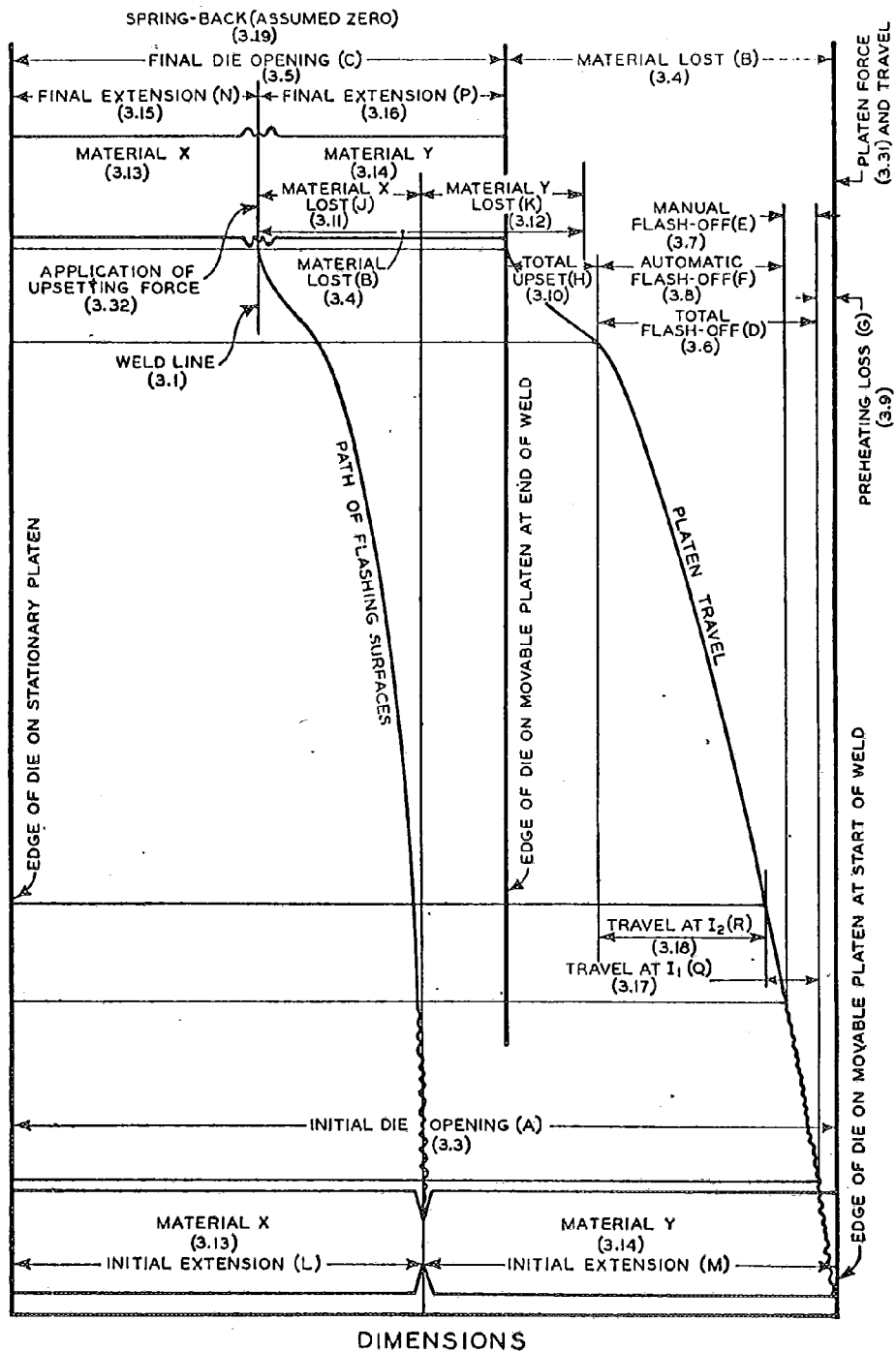


Fig. 3.1—Chart of Flash

(See Par.

Flash Welding

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Welding Definitions

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- 3.25—*Upsetting Current Time* (sec.) is the time during which upsetting current flow is taking place.
- 3.26—*Upsetting Time* (sec.) is the time during which upsetting is taking place.
- 3.27—*Welding Time* (sec.) is the time during which flashing and upsetting is taking place.
- 3.28—*Postheating Time* (sec.) is the time during which postheating is taking place.
- 3.29—*Clamp-Holding Time* (sec.) is the time measured from the end of the postheating time (or end of upsetting time when no postheat is used) to the time at which the clamping force is released from the workpieces.
- 3.30—*Welding Period* (sec.) is the time that elapses from the start of the preheating time to the end of the clamp-holding time.
- 3.31—*Platen Force* (lb.) is the force available at the movable platen to cause upsetting. This force may be dynamic, theoretical or static.
- 3.32—*Upsetting Force* (lb.) is the force exerted at the welding surfaces during upsetting.
- 3.33—*Clamping Force* (lb.) is the force exerted on the dies by the clamping system.
- 3.34—*Preheating Force* (lb.) is the force exerted on the welding surfaces during preheating.
- 3.35—*Preheating Current* (amp.) is the current that flows through the workpieces during preheating.
- 3.36—*Flashing Current* (rms. amp.) is the current that flows through the workpieces during flashing.
- 3.37—*Upsetting Current* (rms. amp.) is the current that flows through the workpieces during upsetting.
- 3.38—*Postheating Current* (rms. amp.) is the current that flows through the workpieces during postheating.
- 3.39—*Secondary Voltage* (E , rms. v.) is the open-circuit voltage of the welding transformer measured on the secondary side.
- 3.40—*Load Voltage* (V , volts) is the voltage across the workpieces while welding and postheating.
- 3.41—*Instantaneous Rate of Flash-off* (in. per sec.) 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.
- 3.42—*Average Rate of Flash-off* (in. per sec.) is the average velocity of one workpiece relative to the other during the entire flashing action.

- 3.43—*Instantaneous Velocity of Upset* (in. per sec.) 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.
- 3.44—*Average Velocity of Upset* (in. per sec.) is the average velocity of one workpiece relative to the other during the entire upsetting action.
- 3.45—*Flashing Time* is the time during which the flashing action is taking place.

304. DISCUSSION OF VARIABLES

304.1 Dimensional Measurements

Dimensions of *Material Lost*; *Material X Lost*; *Material Y Lost*; *Initial Extension, Material X*; *Initial Extension, Material Y*; *Final Extension, Material X*; and *Final Extension, Material Y* are usually obtained by scale measurement of the workpieces before and after welding.

Dimensions of *Initial Die Opening*; *Final Die Opening*; *Total Flash-Off*; *Manual Flashing*; *Automatic Flashing*; *Preheating Loss*; *Travel at I_1* ; and *Travel at I_2* are usually obtained by scale measurement of such items on the welding machine.

The *Total Upset* is most accurately measured by subtracting the sum of the measurements of *Total Flash-Off* and *Preheating Loss* from the measurement of *Material Lost*. The high speed of upsetting together with the error introduced by *Spring-Back* of the machine makes it difficult to measure the Total Upset directly and accurately.

The dimension of *Spring-Back* is difficult to measure directly and fortunately is not important as a weld variable. It assumes more importance as an equipment variable.

304.2 Time Measurements

The time intervals of *Preheating Time*; *Manual Flashing Time*; *Automatic Flashing Time*; *Time at Flashing Current I_1* ; *Time at Flashing Current I_2* ; *Welding Time*; *Postheating Time*; and *Welding Period* can usually be measured with a stop-watch with sufficient accuracy, or can be taken from the chart of a recording instrument such as an oscillograph, recording ammeter, recording wattmeter, etc.

The *Upsetting Current Time* can be taken from the records of an oscillograph or recording ammeter, depending on the length of the time and accuracy desired.

The *Upsetting Time* can be most conveniently taken from the record of a Platen Movement Recorder.

The *Clamp-Holding Time* can be obtained by the use of a dial or chart-type cycle counter.

304.3 Force Measurements

The *Platen Force* and *Upsetting Force* are of a transient nature and are influenced by the method of applying the forces, by friction, by inertia and by the opposing reaction of the material being upset. Consequently, it is difficult to obtain precise measurement of such forces without elaborate strain gages, etc. There are no well-recognized simple approximate methods of measurement in use.

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

304.4 Current Measurements

Preheating Current and *Postheating Current* can be measured by indicating or recording ammeters or oscillographs.

The *Flashing Current* is very irregular due to the flashing action of the

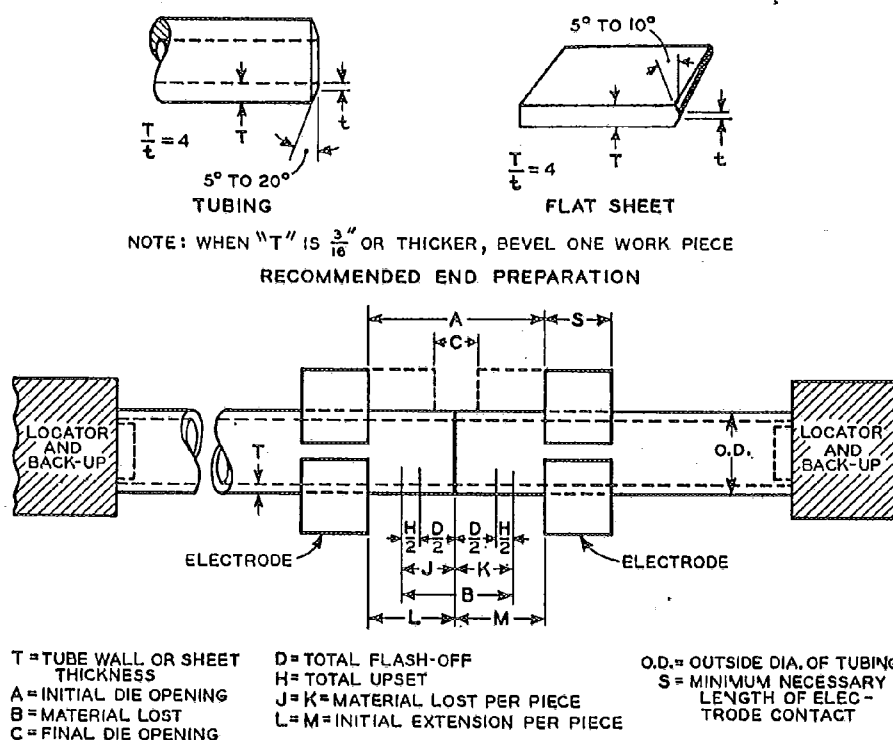


Fig. 3.2—Flash Welding of Tubing and Flat Sheets
 (See Table 3.1 for Recommended Data)

weld. While an oscillograph record is an accurate indication of this current, such records are difficult to analyze readily. Records taken with recording ammeters are usually sufficiently accurate and permit easier analysis to the extent that such records are in common use. To transfer

data from one welding schedule to another by means of recording ammeters requires that such ammeters have equivalent damping characteristics. Standard methods are being developed for the calibration of the damping characteristics of recording ammeters.

Upsetting Current can be precisely measured by an oscillograph or by pointer-stop ammeters for a slightly less, but generally satisfactory, degree of accuracy.

304.5 Voltage Measurements

Secondary Voltage can be measured using an indicating voltmeter.

The *Load Voltage* is as irregular as the *Flashing Current* and a recording voltmeter can be used to measure this load voltage.

304.6 Rates and Velocities of Flash-Off and Upset

The *Average Rate of Flash-Off* can be calculated from the *Flash-Off*

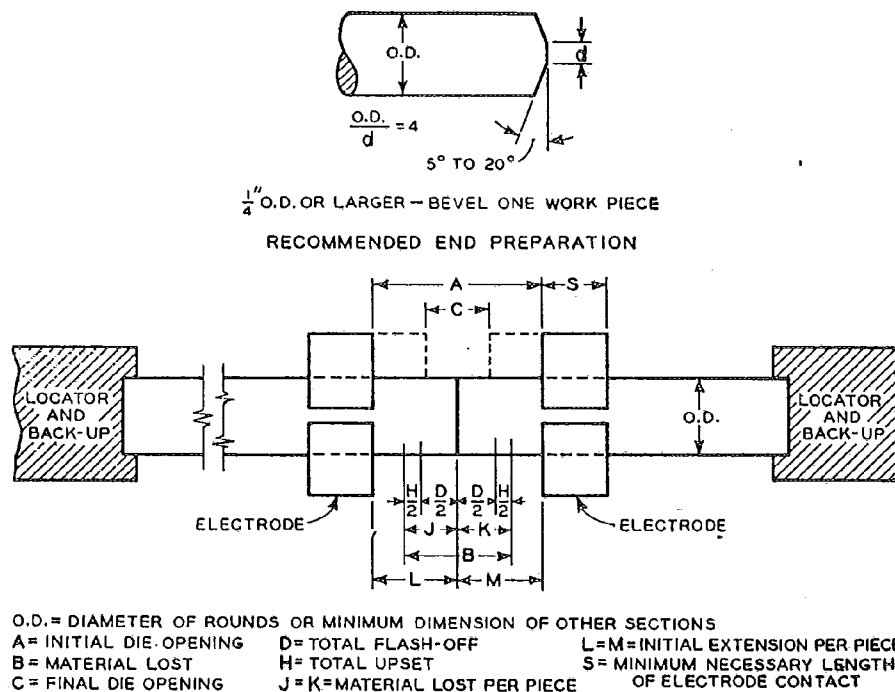


Fig. 3.3—Flash Welding of Solid Round, Hex, Square and Rectangular Bars
(See Table 3.2 for Recommended Data)

Time and the Total Flash-Off.

The *Instantaneous Rate of Flash-Off*, the *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.

Table 3.1—Data for Flash Welding of Tubing and Flat Sheets
(See Fig. 3.2 for Assembly of Parts)

T INCHES	A INCHES	B INCHES	C INCHES	D INCHES	H INCHES	J=K INCHES	L=M INCHES	FLASHING TIME SECONDS	O.D. INCHES	S WITH LOCATOR	S WITHOUT LOCATOR
0.010	0.110	0.060	0.050	0.040	0.020	0.030	0.055	0.40	0.250	0.375	1.00
0.020	0.215	0.115	0.100	0.080	0.035	0.058	0.108	0.80	0.312	0.375	1.00
0.030	0.325	0.175	0.150	0.125	0.050	0.088	0.163	1.25	0.375	0.375	1.50
0.040	0.430	0.230	0.200	0.165	0.065	0.115	0.215	1.75	0.500	0.375	1.75
0.050	0.530	0.280	0.250	0.205	0.075	0.140	0.265	2.25	0.750	0.500	2.00
0.060	0.620	0.330	0.290	0.240	0.090	0.165	0.310	2.75	1.000	0.750	2.50
0.070	0.715	0.385	0.330	0.280	0.105	0.193	0.358	3.50	1.50	1.000	3.00
0.080	0.805	0.435	0.370	0.315	0.120	0.218	0.403	4.00	2.00	1.250	
0.090	0.885	0.475	0.410	0.345	0.130	0.238	0.443	4.50	2.50	1.750	
0.100	0.970	0.520	0.450	0.375	0.145	0.260	0.485	5.00	3.00	2.000	
0.110	1.060	0.570	0.490	0.410	0.160	0.285	0.530	5.75	3.50	2.25	
0.120	1.140	0.610	0.530	0.440	0.170	0.305	0.570	6.25	4.00	2.50	
0.130	1.225	0.650	0.575	0.470	0.180	0.325	0.613	7.00	4.50	2.75	
0.140	1.320	0.700	0.620	0.510	0.190	0.350	0.660	7.75	5.00	2.75	
0.150	1.390	0.730	0.660	0.530	0.200	0.365	0.695	8.50	5.50	3.00	
0.160	1.470	0.770	0.700	0.560	0.210	0.385	0.735	9.00	6.00	3.25	
0.170	1.540	0.800	0.740	0.580	0.220	0.400	0.770	9.75	6.50	3.50	
0.180	1.620	0.840	0.780	0.610	0.230	0.420	0.810	10.50	7.00	3.75	
0.190	1.690	0.870	0.820	0.630	0.240	0.435	0.845	11.25	7.50	4.00	
0.200	1.760	0.900	0.860	0.650	0.250	0.450	0.880	12.00	8.00	4.25	
0.250	2.010	1.010	1.000	0.730	0.280	0.505	1.005	16.00	8.50	4.50	
0.300	2.245	1.120	1.125	0.810	0.310	0.560	1.123	21.00	9.00	4.75	
0.350	2.460	1.210	1.250	0.880	0.330	0.605	1.230	27.00	9.50	5.00	
0.400	2.640	1.290	1.350	0.930	0.360	0.645	1.320	33.00	10.00		
0.450	2.780	1.350	1.430	0.970	0.380	0.675	1.390	38.00			
0.500	2.910	1.410	1.500	1.020	0.390	0.705	1.455	45.00			
0.550	3.040	1.465	1.575	1.055	0.410	0.733	1.520	50.00			
0.600	3.135	1.505	1.630	1.085	0.420	0.753	1.568	56.00			
0.650	3.245	1.555	1.690	1.125	0.430	0.778	1.623	63.00			
0.700	3.360	1.610	1.750	1.160	0.450	0.805	1.680	70.00			
0.800	3.525	1.675	1.850	1.210	0.465	0.838	1.763	83.00			
0.900	3.660	1.730	1.930	1.250	0.480	0.865	1.830	97.00			
1.000	3.800	1.800	2.000	1.300	0.500	0.900	1.900	110.00			

NOTE:

DATA BASED ON WELDING WITHOUT PREHEAT, AND FOR TWO PIECES
OF SAME WELDING CHARACTERISTICS

Flash Welding

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Table 3.2—Data for Flash Welding of Solid Round, Hex, Square and Rectangular Bars
(See Fig. 3.3 for Assembly of Parts)

O.D. INCHES	A INCHES	B INCHES	C INCHES	D INCHES	H INCHES	J=K INCHES	L=M INCHES	FLASHING TIME SECONDS	O.D. INCHES	S WITH LOCATOR	S WITHOUT LOCATOR
0.050	0.100	0.050	0.050	0.040	0.010	0.025	0.050	0.40	0.250	0.375	1.00
0.100	0.182	0.082	0.100	0.082	0.020	0.041	0.091	0.75	0.312	0.375	1.00
0.150	0.270	0.120	0.150	0.090	0.030	0.060	0.135	1.15	0.375	0.375	1.50
0.200	0.350	0.150	0.200	0.110	0.040	0.075	0.175	1.50	0.500	0.375	1.75
0.250	0.430	0.180	0.250	0.130	0.050	0.090	0.215	1.90	0.750	0.500	2.00
0.300	0.510	0.210	0.300	0.150	0.080	0.105	0.255	2.25	1.000	0.750	2.50
0.350	0.600	0.250	0.350	0.180	0.070	0.125	0.300	2.75	1.50	1.000	3.00
0.400	0.685	0.285	0.400	0.205	0.080	0.143	0.343	3.25	2.00	1.25	
0.450	0.770	0.320	0.450	0.230	0.090	0.160	0.385	3.75	2.50	1.75	
0.500	0.850	0.350	0.500	0.250	0.100	0.175	0.425	4.25	3.00	2.00	
0.550	0.940	0.390	0.550	0.280	0.110	0.195	0.470	5.00	3.50	2.25	
0.600	1.025	0.425	0.600	0.305	0.120	0.213	0.513	5.50	4.00	2.50	
0.650	1.100	0.450	0.650	0.325	0.125	0.225	0.550	6.75	4.50	2.75	
0.700	1.180	0.480	0.700	0.350	0.130	0.240	0.590	7.50	5.00	2.75	
0.750	1.260	0.510	0.750	0.375	0.135	0.255	0.630	8.25	5.50	3.00	
0.800	1.340	0.540	0.800	0.400	0.140	0.270	0.670	9.00	6.00	3.25	
0.850	1.420	0.570	0.850	0.425	0.145	0.285	0.710	9.75	6.50	3.50	
0.900	1.500	0.600	0.900	0.450	0.150	0.300	0.750	10.50	7.00	3.75	
0.950	1.580	0.630	0.950	0.475	0.155	0.315	0.790	11.75	7.50	4.00	
1.000	1.660	0.660	1.000	0.500	0.160	0.330	0.830	13.00	8.00	4.25	
1.050	1.740	0.690	1.050	0.525	0.165	0.345	0.870	14.75	8.50	4.50	
1.100	1.820	0.720	1.100	0.550	0.170	0.360	0.910	16.50	9.00	4.75	
1.150	1.900	0.750	1.150	0.575	0.175	0.375	0.950	18.25	9.50	5.00	
1.200	1.980	0.780	1.200	0.600	0.180	0.390	0.990	20.00	10.00		
1.250	2.060	0.810	1.250	0.625	0.185	0.405	1.030	22.50			
1.300	2.140	0.840	1.300	0.650	0.190	0.420	1.070	25.00			
1.400	2.300	0.900	1.400	0.700	0.200	0.450	1.150	30.00			
1.500	2.460	0.960	1.500	0.750	0.210	0.480	1.230	36.00			
1.600	2.620	1.020	1.600	0.800	0.220	0.510	1.310	45.00			
1.700	2.780	1.080	1.700	0.850	0.230	0.540	1.390	54.00			
1.800	2.940	1.140	1.800	0.900	0.240	0.570	1.470	63.00			
1.900	3.100	1.200	1.900	0.950	0.250	0.600	1.550	75.00			
2.000	3.260	1.260	2.000	1.000	0.260	0.630	1.630	90.00			

NOTES:

1. DATA BASED ON WELDING WITHOUT PREHEAT, AND FOR TWO PIECES OF SAME WELDING CHARACTERISTICS
2. VALUES APPLY ONLY WHERE RATIO OF MAXIMUM TO MINIMUM CROSS-SECTIONAL DIMENSION DOES NOT EXCEED 1.5 TO 1.0

305. CLASSIFICATION OF STEELS FOR FLASH WELDING

The values of the *Upsetting 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 of applying the flash welding process to steels, such steels are classified as follows and typical steels of the various classes are given.

LOW FORGING STRENGTH STEELS

This class is typified by SAE 1020, SAE 1112, SAE X1112, SAE X1315 and those steels commonly designated as "High-Strength Low-Alloy Steels".

MEDIUM FORGING STRENGTH STEELS

This class is typified by SAE 1045, SAE 1065, SAE X1335, SAE 3135, SAE 4130, SAE 4140, etc.

HIGH FORGING STRENGTH STEELS

This class is typified by SAE X4340, SAE 4640, stainless iron (12% chrome type), stainless steel (18-8 type), stainless steel (cutlery type), high-speed steel, special tool, die and austenitic valve stem steels.

EXTRA HIGH FORGING STRENGTH STEELS

This class is typified by all steels exhibiting extra high compressive strengths at elevated temperatures.

306. FLASH WELDING SCHEDULES

Flash welding schedules for welding tubing and flat sheets having thicknesses ranging from 0.010 to 1.00 in. are given in Fig. 3.2 and Table 3.1 and cover steels of Low and Medium Forging Strength.

Flash welding schedules for welding solid round, hex, square and rectangular bars having an outside diameter of rounds or minimum dimension of other sections ranging from 0.050 to 2.00 in. are given in Fig. 3.3 and Table 3.2 and cover steels of Low and Medium Forging Strength.

These schedules show the necessary dimensions for setting up a flash welding machine to weld such sections and the total flashing time based on welding without preheating.

No data are available as to the necessary Flashing Current, rates and velocities of Flashing and Upset required.

When setting up a schedule, the dimensionable variables and flashing time are selected from the tabulations and the machine voltage regulator adjusted to give the lowest Secondary Voltage, E , at which steady and consistent flashing can be obtained. The flashing current resulting from such voltage setting will then be at a satisfactory value.

The Secondary Voltage, E , to obtain this satisfactory Flashing Current,

is dependent on the electrical characteristics of the welding machine being used.

The Upsetting Forces used for the schedules are dependent upon the class of steel as well as on 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, i.e., no pre-heating:

Low Forging Strength Steels—10,000 psi. of weld sectional area.

Medium Forging Strength Steels—15,000 psi. of weld sectional area.

High Forging Strength Steels—25,000 psi. of weld sectional area.

Extra High Forging Strength Steels—35,000 psi. of weld sectional area.

307. SURFACE FINISH

Surfaces of parts between the electrodes or contacting the electrodes should be free of dirt, scale, paint, oil or grease, and smooth enough to obtain an adequate area and distribution of contact.

IV. RECOMMENDED PRACTICE FOR SPOT WELDING MAGNESIUM ALLOYS

401. MATERIAL CHARACTERISTICS

The electrical and thermal conductivities of magnesium alloys are generally lower than those of aluminum alloys, requiring some adjustment of welding conditions to accomplish similar results. Typical machine settings used in spot welding aluminum develop more heat when applied to magnesium alloys of the same gage.

In some cases, alloys come with various protective and/or conversion coatings requiring an extra precleaning or stripping step in the cleaning operation prior to the normal sequence. Graphite lubricating compounds used in forming operations similarly require a precleaning operation for best results.

Untreated magnesium alloys rapidly form oxide films producing a high and inconsistent surface resistance necessitating a cleaning and deoxidizing treatment immediately prior to spot welding.

The resistance of magnesium alloys to caustic attack allows the use of higher concentrations of alkaline cleaner than those used with aluminum alloys.

Cleaned magnesium surfaces are sensitive to moisture during the spot welding operation. Condensation on the electrodes or moisture on the surface will require more frequent cleaning of the electrodes to reduce "tip pick-up".

Mechanical cleaning is usually accomplished in a manner that will not produce undue heating of the surface being cleaned.

402. SURFACE PREPARATION

402.1 Purpose

Proper surface cleaning is necessary to provide a uniform high electrical conductivity on the outer surface at the electrode interface and a uniform low resistance of approximately 50 microhms or less at the faying surfaces to be spot welded so that a developed weld schedule will produce welds of uniform diameter, penetration, and quality.

The electropositive nature of magnesium alloys contributes to rapid surface film formations and limits the time between cleaning and welding if uniform results are to be obtained. This time interval is determined as a function of the relative exposure of the cleaned weld surfaces, the cleanliness conditions of the area, the quality and the consistency demands placed on the welds, and the cleaning process used. As a general rule, best results can be obtained on critical welds (e.g., welds which affect

the proper functioning or safety of a piece of equipment) if the time between cleaning and welding is limited to 24 hours for chemical cleaning and 8 hours for mechanical cleaning. For noncritical welds, this time may be extended to 96 hours and 22 hours, respectively.

402.2 Chemical Cleaning

The chemical cleaning process is favored for production operations for obvious economic and process control reasons. A further advantage, as shown in Table 4.1, is the extended tip life obtained when parts are cleaned chemically rather than mechanically.

Material conditions and part processing frequently make a preliminary cleaning operation necessary. This stripping and/or precleaning operation is preliminary to the usual process which consists of an alkaline cleaning bath followed by an oxide removal bath. Parts which have conversion coatings, deposits of graphite forming lubricants, or are oil or grease coated, should be given this preliminary treatment to insure a uniformly deoxidized surface when processed by the conventional cleaning sequence.

Table 4.1—Spot Weld Tip Life as a Function of Metal Preparation

ASTM alloy designation	RWMA electrode classification	Approximate Tip Life (Number of Spots) with Indicated Surface Preparation		
		wire brush	sulfuric pickle	chromic pickle
AZ31B	Class 1	30	>200	>550
AZ31B	Class 2	15	50	270
HK31A	Class 2	40	400	195
HM21A	Class 2	5	80	5
ZE10A	Class 2	10	35	25

402.2.1 CHEMICAL CLEANING EQUIPMENT

Typical material requirements for tanks to be used with various cleaning solutions are given in Table 4.2.

It is desirable to provide a thermostatic control of the solution temperatures in order to maintain them within specified limits.

Adequate handling equipment, e.g., baskets or racks, to transport the parts from solution to solution during the cleaning process is essential.

When using hot alkaline or deoxidizing solutions, spray nozzles are sometimes employed to furnish a partial water rinse to preclude the drying-on of the solutions on the hot parts.

Air agitation may be incorporated by using perforated pipes along the bottom of the tanks. The air supply should be filtered to prevent contamination of the solution by rust, oil, grease and dirt from the supply lines.

Various types of timing devices such as adjustable timers with audible buzzers or bells are used to indicate the elapsed immersion time.

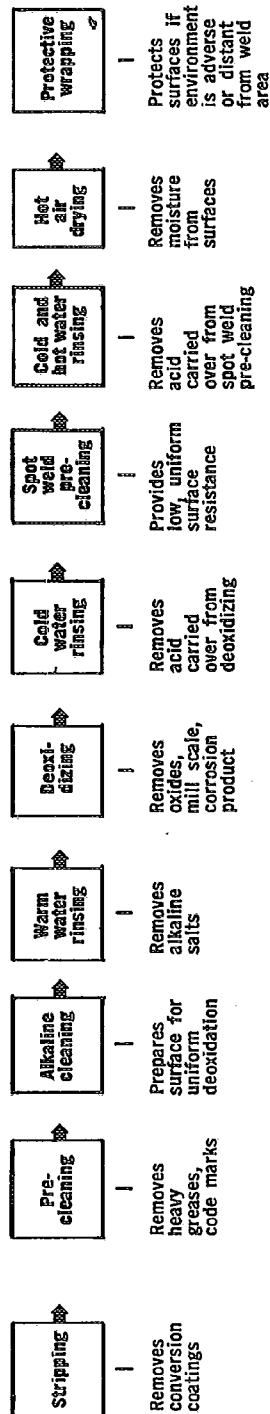
402.2.2 CHEMICAL CLEANING PROCESS STEPS

The basic flow chart for cleaning magnesium alloys is shown in Fig. 4.1. The descriptive sequence which follows is based on the steps summarized in the chart:

(a) *Stripping* — Many magnesium alloys are furnished with conversion coatings. These coatings are stripped prior to processing the parts

Table 4.2—Tank Materials for Various Cleaning Solutions

Cleaning solution	Suitable Tank Materials (+)							
	Steel	316 Stain- less	1100 Alum- inum	Lead	Vinyl- lined steel	Syn- thetic rubber	Ce- ramic	Glass
<i>Precleaning:</i>								
Vapor degreaser	+	—	—	—	—	—	—	—
Emulsion cleaner	+	—	—	—	—	—	—	—
<i>Rinsing:</i>								
Water	+	+	—	—	+	—	—	—
<i>Alkaline cleaning:</i>								
Sodium hydroxide	+	—	—	—	—	—	—	—
General alkaline cleaners	+	—	—	—	—	—	—	—
<i>Deoxidizing:</i>								
Chromic nitrate	—	+	+	+	+	—	—	—
Chromic-nitric hydrofluoric	—	+	—	—	+	—	—	—
Chromic-sulfuric	—	+	—	+	+	—	+	—
Sulfuric	—	—	—	+	+	+	+	—
Chromic acid	—	+	+	+	—	—	+	+
Ferric nitrate	—	+	—	—	+	+	—	—
Acetic nitrate	—	—	+	—	—	+	+	—
Phosphoric	—	—	—	+	—	+	+	+
<i>Spot weld precleaning:</i>								
Chromic-sulfuric	—	+	—	+	+	—	+	—
Dilute chromic acid	—	+	+	+	+	—	+	+



APPLICABLE CLEANING SOLUTIONS

	Vapor degrease	Sodium hydroxide	Water	Chromic-nitrate	Water	Chromic-sulfuric	Water	Air
No metal loss				Chromic-nitrate		Dilute chromic acid		
1. Chromic acid	Commercial emulsion cleaners such as:	Commercial alkaline cleaners such as:		Chromic-nitric-hydro-fluoric				
2. Sodium hydroxide (except Dow 17 or HAE coatings)	1. Aero-wash A 2. Diversey DC-16	1. Oakite 90, 154, 61, 61A 2. Kelite Anodyne		Chromic-sulfuric				
Minor metal loss				Sulfuric				
1. Chromic-nitrate		3. Turco 2623, 3256, 4020		Nitric-sulfuric				
2. Chromic-nitric-hydro-fluoric		4. Wyandotte Max. Amp., Actrex-B		Ferric-nitrate				
3. Chromic-sulphuric		5. Diversey 808		Acetic-nitrate				
		6. Penn Salt A-27		Phosphoric				
				Chromic acid				

The cleaners listed in this figure are typical. It is not intended by such listing to infer that other commercial cleaning compounds are not suitable.

Fig. 4.1—Magnesium Cleaning Flow Chart

through the normal cleaning sequence. The solutions suitable for stripping are given in Fig. 4.1. These solutions are also used on hot formed magnesium parts to remove graphite particles deposited from forming lubricants.

(b) *Precleaning* — Parts and sheets with heavy surface contamination such as greases, code markings etc., are processed through a precleaning operation which can be either vapor degreasing or an emulsion type cleaner.

(c) *Alkaline cleaning* — The resistance of magnesium alloys to caustic attack allows the use of high concentrations of sodium hydroxide in alkaline cleaners giving a more effective action. Most commercial alkaline cleaners used on steel and some of the alkaline cleaners used on aluminum may be used for magnesium.

(d) *Hot Water Rinsing* — It is important to rinse the parts coming from the alkaline cleaning solution in warm water to remove all alkaline salts to prevent carry-over into the deoxidizer solution. This carry-over forms an oily, soapy film on the surface of the deoxidizer solution which redeposits, contaminating the parts as they are removed from the tank.

(e) *Deoxidizing* — Many suitable solutions are available for deoxidizing magnesium alloys. Some of these are listed in Table 4.3 which gives typical compositions, operating temperatures and immersion times. In addition to these, many commercial products are available as recommended by the magnesium suppliers.

The short immersion times required with some solutions and concentrations make them primarily applicable to small quantities of hand-dipped parts.

(f) *Cold Water Rinsing* — Cold water rinsing is employed after the deoxidizing step to prevent deoxidizer carry over into the spot weld precleaning bath. Such carry-over will destroy the effectiveness of the precleaning bath so that it will be necessary to replace it at more frequent intervals.

(g) *Spot Weld Precleaning* — Although some of the deoxidizer cleaning solutions as pointed out in Table 4.3 can also be used for spot weld precleaning, the longest electrode tip life will be obtained by using the precleaners specifically designed for this purpose. Suitable spot weld precleaners are indicated at the bottom of Table 4.3. In addition to these, several proprietary formulations are also available from various suppliers.

The purpose of spot weld precleaning is to provide a uniformly low surface resistance. A bright finish does not necessarily indicate low surface resistance. Properly applied, chromic-sulfuric precleaning will leave a frosty appearance while dilute chromic acid precleaning will leave a slight brassy color on the parts.

(h) *Cold & Hot Water Rinsing & Air Drying* — Thorough rinsing and drying of the parts is required if proper results are to be obtained. Precleaner residues on the metal surface will produce a nonuniform sur-

Table 4.3—Composition of Cleaning Solutions

Cleaning solution, type	Composition	Temp, deg F	Immersion time	Remarks
<i>Deoxidizing*:</i>				
Chromic-nitrate	Chromic acid 24 oz/gal Sodium Nitrate 4 oz/gal	70-90	3-5 min	Used to remove graphite forming lubricants. Can be used as spot weld precleaner for some alloys but is not as effective as spot weld precleaners listed below.
Chromic-nitric-hydrofluoric	Chromic acid 37.5 oz/gal Nitric acid (70%) 3.25 fl oz/gal Hydrofluoric acid (60%) 1 fl oz/gal	70-90	½-2 min	Used for acid pickling of castings, particularly die castings.
Chromic-sulfuric	Chromic acid 24 oz/gal Sulfuric acid (conc) 0.065 fl oz/gal	70-90	2-4 min	For deoxidizing wrought products. Also suitable as spot weld precleaner (see below).
Sulfuric	Sulfuric acid (conc) 4 fl oz/gal	70-90	15 sec	Used on sand castings to remove effect of sand, shot or grit blasting.
Ferric-nitrate	Chromic acid 24 oz/gal Ferric nitrate 5.3 oz/gal Potassium fluoride 0.47 oz/gal	70-90	1-4 min	Bright pickle for all magnesium alloys and forms. Can be used as spot weld precleaner on some alloys, but is not as effective as spot weld cleaners listed below.
Acetic-nitrate	Glacial acetic acid 25.5 fl oz/gal Sodium nitrate 6.67 oz/gal	70-90	½-1 min	For removal of mill scale from magnesium sheet.
Phosphoric	Phosphoric acid (85%) 0.9 gal/gal	70-80	30 sec	For preparing die cast surfaces for chemical treating.
Chromic acid	Chromic acid 24 oz/gal	70-boiling	1-5 min	Removes corrosion products and old chemical treatments from all forms of magnesium.
<i>Spot weld precleaning:</i>				
Chromic-sulfuric	Chromic acid 24 oz/gal Sulfuric acid (conc) 0.065 fl oz/gal	70-90	2-4 min	Provides longest electrode tip life on ZE10A and the Mg-Th alloys, e.g., HK31A, HM21A, of any precleaning method (see Table 4.1).
Dilute chromic acid	Chromic acid 0.33 oz/gal	70-90	30 sec	Provides longest electrode tip life on Mg-Al-Zn alloys, e.g., AZ31B, of any precleaning method (see Table 4.1).

* For removal of heavy oxide films, mill scale, corrosion product, etc. prior to cleaning with a spot weld precleaner

face resistance and cause erratic welding results. Moisture on the surface of the part will reduce electrode tip life. Consequently it is important that surfaces for spot welding be completely dry.

402.2.3 CLEANING SOLUTION MAINTENANCE AND CONTROL

Once the optimum limits of concentration, temperature, and immersion time have been established and the process is in use, some type of a solution maintenance and control program should be established to support operation within these limits. This maintenance usually consists of:

- (a) A daily temperature check to monitor the operation of thermostatic controls
- (b) A biweekly solution analysis followed by written instructions directing the addition of quantities of concentrates necessary to bring the solution to optimum concentration
- (c) Directions for total replacement of solutions at required intervals to prevent staining of parts after too many corrective additions of concentrates
- (d) Surface resistance measurements to determine that the overall cleaning process is compatible with that used at the time of establishment of weld machine settings.

402.3 Mechanical Cleaning

Mechanical cleaning of magnesium alloys is used for:

- (a) Small quantities or pilot parts requiring very few welds where the installation of a chemical cleaning system is not economically justified or is not available
- (b) Cleaning of parts and adjoining surfaces on partial assemblies where it is undesirable to immerse the complete assembly in a solution

The mechanical cleaning process is accomplished by first removing any grease, oil or protective coatings in the local areas of the welds by manual application of chemical strippers. After thorough rinsing and drying, the areas are wire brushed using a stainless steel bristle brush or rubbed with stainless steel wool. Wire brushing is sometimes restricted to hand brushing to avoid overheating of the surfaces of the material being cleaned.

403. WELD-THROUGH SPOT WELD SEALING

Weld-through spot weld sealers are frequently used to seal or protect faying joint surfaces from corrosive environments. Standard preweld cleaning procedures are used on the base metal prior to application of the sealer as the sealer provides no cleaning action. Sealers should not be so viscous as to prevent base metal contact at the faying surface when the correct pressure is applied by the welding electrodes. The time between application of the sealer and welding should be minimized, especially in catalyst-activated sealers, to avoid sealer entrapment and/or weld expulsion caused by "setting" of the sealer. Certain postweld finishing treatments, e.g., alkaline cleaning, degreasing, alkaline anodizing, require the use of a catalyst-activated sealer rather than an air-drying sealer as the latter

tends to be leached out of the joint by the treatment unless it is thoroughly dry (set). The speed of drying in air-dry sealers may be enhanced by forced drying at temperatures up to 250 F. Higher temperatures will cause rapid evolution of the solvent which will disrupt the continuity of the sealer. Table 4.4 lists several proprietary weld-through sealers currently in use on magnesium. Other sealers may be suitable for magnesium but they should be evaluated before being used on production parts.

Table 4.4—Spot Weld Sealers* for Magnesium

The sealers listed in this table are typical. It is not intended by such listing to infer that other commercial spot weld sealers are not suitable.

Trade name	Manufacturer	Remarks
EC 801/807	Minnesota Mining & Manufacturing Company, St. Paul, Minnesota	Catalyst activated. Will withstand all standard chemical treatments for magnesium.
EC 1749	Minnesota Mining & Manufacturing Company, St. Paul, Minnesota	Air drying. Alkaline type cleaning treatments and standard degreasing methods will leach out sealer unless it has completely air dried.
Presstico #273	Presstite Engineering Company, St. Louis, Missouri	Air drying. Alkaline type cleaning treatments and standard degreasing methods will leach out sealer unless it has completely air dried.

* These sealers have been successfully applied to magnesium. Other sealers may be applicable but should be evaluated first.

404. WELDING SCHEDULES

404.1 General

From the dimensions, properties and characteristics of the alloys to be welded, the specific type of welding equipment to be employed and the joint design involved, it is possible to establish a welding schedule for any particular combination of these variables. With the obvious multiplicity of variables involved it is impractical to prespecify welding schedules for every conceivable condition and combination. However, for the most commonly welded thicknesses of similar alloys, industry data have been compiled by the AWS Resistance Welding Committee to serve as a guide. These recommended practices are shown in Tables 4.5 to 4.8, inclusive.

The schedules have been compiled to provide uniform information for use by the design, manufacturing and inspection departments. In order

to obtain uniform production, it is necessary that these three groups employ the same welding data because of the interrelated requirements of design, welding practice and results produced. The designer must be guided in choice of overlap, flange width, weld spacings and weld strengths by the equipment and conditions to be employed in the manufacture of the product. To assure that the anticipated weld strengths are achieved, the manufacturing units should employ the applicable factors of the schedule — electrode dimensions, force, current and time as specified.

404.2 Setup Procedure for Three-Phase Converter Machines (Supplementing Table 4.5)

- (a) Insert electrodes of recommended size and contour for the thickness combination to be welded and provide recommended electrode force.
- (b) Check the force at the electrodes for magnitude and consistency with a force gage.
- (c) Adjust the control to obtain the recommended approximate weld and postheat times. A schematic representation of standard AWS terms used to define the weld heat cycle of frequency converter welding machines is given in Fig. 4.2.
- (d) If forging is to be used, the current-force relationship must be adjusted by means of the forge-delay time to provide forging at the correct time. Fig. 4.3 shows a typical current-force diagram for three-phase converter type machines. Refer to text on Welding Force (Par. 405.3) for detailed information.
- (e) The welding currents, weld and postheat, shown are approximate and intended to be a guide. The welding currents are seldom indicated on the machine and are generally not measured on this type of equipment. The magnitude of the welding current is usually controlled by a heat dial or phase shift heat control when current measuring equipment is not used. To obtain the required current, simply start with a low value of weld heat and corresponding recommended percentage of postheat, and make and test single-spot shear specimens, increasing the current until the desired shear strength, weld diameter and penetration are obtained. In some cases it may be necessary to readjust weld time to achieve the desired results.
- (f) Check the machine for consistency of operation by making and testing 20 single-spot shear specimens and 5 specimens for macroscopic examination. A variation of $\pm 12\frac{1}{2}\%$ in 90% of the specimens and $\pm 25\%$ in the balance is considered good.
- (g) The machine settings obtained constitute an individual machine schedule and should be recorded for future reference.
- (h) The average weld strength and fused zone diameters shown indicate what may be obtained for definite conditions of surface preparation, fit-up and other factors. However, consistent welds exceeding minimum strength requirements are satisfactory.

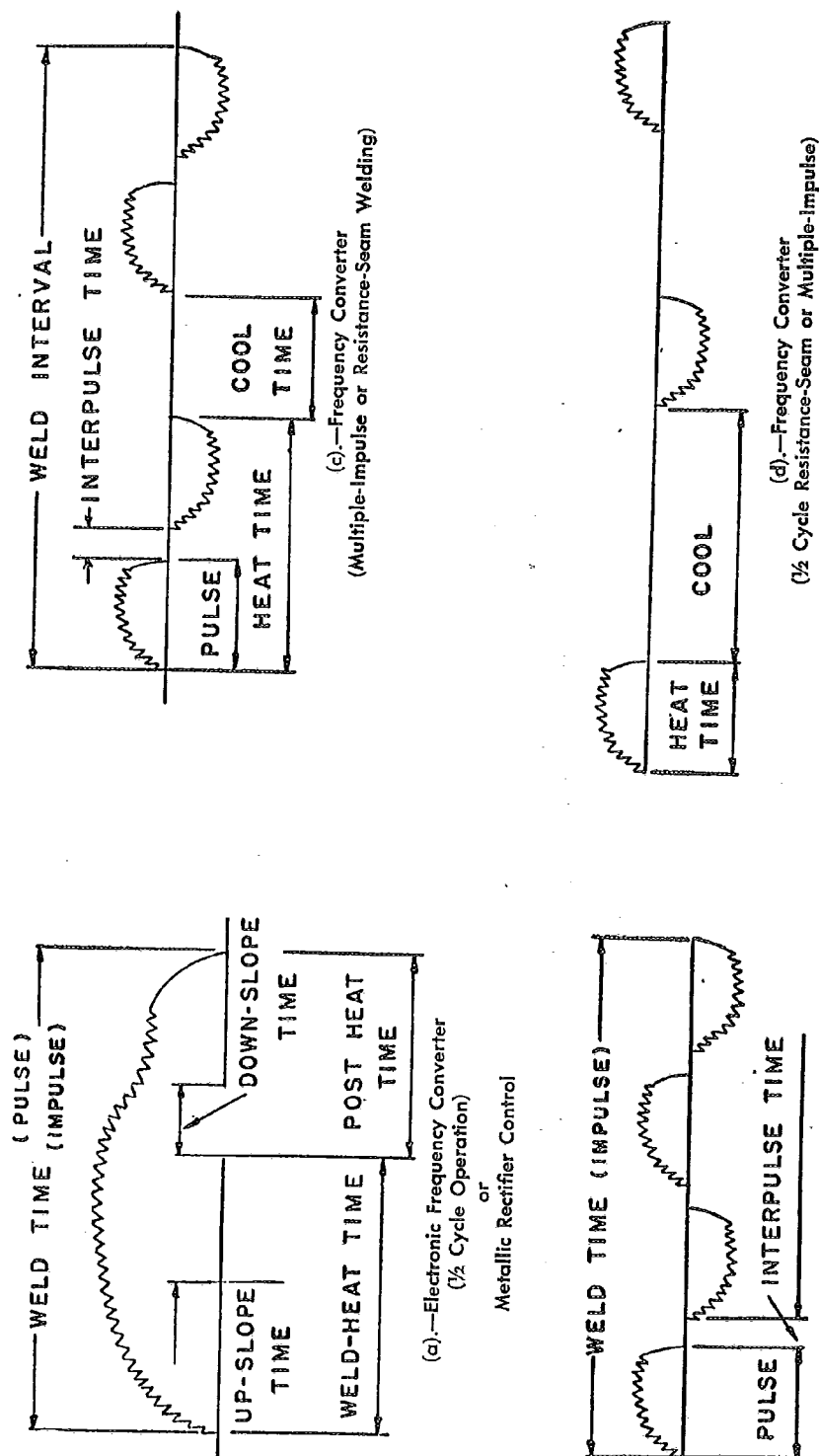
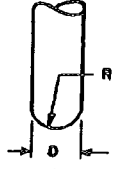


Fig. 4.2—Schematic Representation of Standard AWS Terms Used to Define the Weld Heat Cycle of Frequency-Converter Machines

Table 4.5—Spot Welding Magnesium Alloys on

ASTM ALLOY DESIGN- ATION	MATERIAL THICK- NESS (see note 1)	ELECTRODE DIAMETER AND SHAPE (see note 2) 		NET ELECTRODE FORCE		FORGE DELAY TIME	WELD HEAT CYCLE		
							PULSE TIME	NO. OF PULSES	TOTAL WELD HEAT TIME
	INCHES	D, IN.	R, IN.	WELD LB	FORGE LB	CYCLES (60/SEC)	CYCLES (60/SEC)		CYCLES (60/SEC)
AZ31B	0.020	1/2	3	800	-----	---	1	2	2
	0.025	1/2	3	800	-----	---	1	1	1
	0.032	1/2	3	1,000	-----	---	1	2	2
	0.040	5/8	3	1,200	-----	---	1	2	2
	0.050	5/8	4	1,400	3,500	2	2	2	4
	0.050	5/8	4	1,600	-----	---	2	1	2
	0.063	5/8	4	1,750	-----	---	3	1	3
	0.063	7/8	4	1,200	3,900	3	3	1	3
	0.063	5/8	4	1,200	1,920	3	3	1	3
	0.090	7/8	4	2,000	4,300	2	3	1	3
	0.125	7/8	6	4,500	-----	---	5	6	30
HK31A	0.040	1/2	3	1,000	-----	---	1	1	1
	0.050	5/8	4	1,400	-----	---	2	2	4
	0.063	3/4	4	2,400	-----	---	3	1	3
	0.080	3/4	4	3,400	-----	---	4	1	4
	0.125	7/8	6	5,000	-----	---	5	6	30
	0.125	3/4	6	2,400	3,200	2	5	6	30
HM21A	0.040	1/2	3	800	-----	---	1	2	2
	0.050	5/8	4	1,200	-----	---	2	2	4
	0.063	5/8	4	1,600	-----	---	3	2	6
	0.071	5/8	4	2,200	-----	---	4	2	8
	0.090	3/4	4	3,000	-----	---	4	2	8
	0.125	7/8	6	3,800	-----	---	5	2	10
	0.125	7/8	6	2,000	3,600	5	5	6	30
ZE10A	0.040	5/8	3	1,200	-----	---	1	1	1
	0.050	5/8	4	2,000	-----	---	2	2	4
	0.063	3/4	4	2,400	-----	---	3	1	3
	0.080	3/4	4	2,800	-----	---	4	2	8
	0.125	7/8	6	3,600	-----	---	5	6	30
ZK60A	0.105	3/4	6	3,000	-----	---	5	6	30

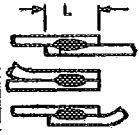
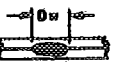
Notes:

1. Thickness of one member of a like-thickness two-member assembly.
2. Where practical, a spherical radius is recommended. This radius should be the same on both the top and bottom electrodes for like thicknesses and material combinations unless the contour of the part is such that unlike radii are necessary to effect a heat balance.
3. Minimum weld spacing that will require no special precautions to be taken for shunted current effect of an adjacent weld.

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Three-Phase Frequency-Converter Type Machines

POST HEAT TIME	WELDING CURRENT APPROX. (see note 5)		MINIMUM CONTACTING OVERLAP (see note 4)	MINIMUM WELD SPACING (see note 3)	DIAMETER OF FUSED ZONE	MINIMUM AVERAGE SHEAR STRENGTH	MATERIAL THICK- NESS (see note 1)	ASTM ALLOY DESIGN ATION
				center to center				
	WELD POSTHEAT							
CYCLES (60/SEC)	AMP	AMP	IN.	IN.	IN.	LB	INCHES	
---	25,400	---	7/16	1/4	0.19	195	0.020	AZ31B
2	20,200	4,000	7/16	1/4	0.14	200	0.025	
---	26,400	---	1/2	5/16	0.20	330	0.032	
---	28,300	---	9/16	3/8	0.21	425	0.040	
5	29,000	10,300	5/8	7/16	0.19	435	0.050	
---	31,000	---	5/8	7/16	0.19	440	0.050	
---	35,200	---	3/4	1/2	0.22	580	0.063	
---	43,600	---	3/4	1/2	0.25	690	0.063	
6	43,600	24,800	3/4	1/2	0.29	800	0.063	
5	42,700	15,000	15/16	3/4	0.26	910	0.090	
---	66,900	---	1-1/8	15/16	0.46	2,095	0.125	
---	19,600	---	9/16	3/8	0.17	310	0.040	HK31A
---	31,600	---	5/8	7/16	0.23	530	0.050	
---	39,400	---	3/4	1/2	0.25	660	0.063	
---	50,500	---	7/8	5/8	0.29	890	0.080	
---	65,900	---	1-1/8	15/16	0.33	1,300	0.125	
---	50,900	---	1-1/8	15/16	0.37	1,380	0.125	
---	21,600	---	9/16	3/8	0.18	355	0.040	HM21A
---	30,700	---	5/8	7/16	0.21	470	0.050	
---	40,600	---	3/4	1/2	0.23	560	0.063	
---	47,400	---	13/16	9/16	0.29	770	0.071	
---	53,200	---	15/16	3/4	0.26	950	0.090	
---	66,700	---	1-1/8	15/16	0.32	1,180	0.125	
---	56,500	---	1-1/8	15/16	0.37	1,405	0.125	ZE10A
---	25,700	---	9/16	3/8	0.20	390	0.040	
---	41,000	---	5/8	7/16	0.28	665	0.050	
---	49,100	---	3/4	1/2	0.29	805	0.063	
---	54,000	---	7/8	5/8	0.31	1,020	0.080	
---	66,700	---	1-1/8	15/16	0.34	1,265	0.125	
---	51,200	---	1	13/16	0.32	1,265	0.105	ZK60A

4. Avoid using contacting overlaps below the value specified, otherwise weld strengths will be difficult to maintain under shop conditions or distortion of the lapping sheets may occur.
5. Refer to step (5) of the "Set-up Procedure For Three-Phase Frequency Converter Machines" which supplements this table.

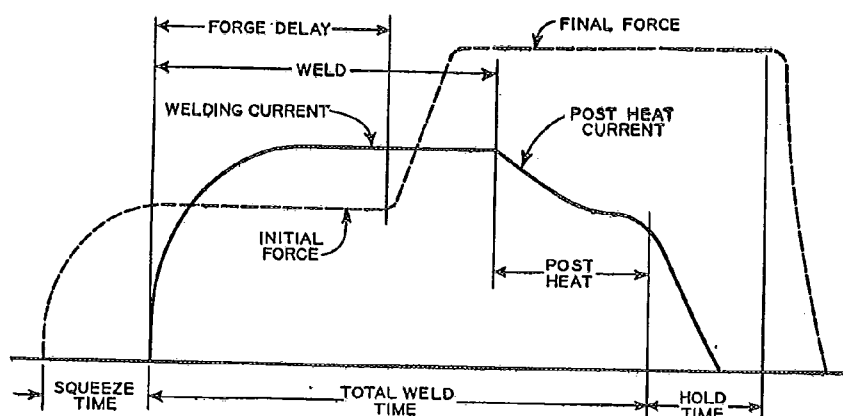


Fig. 4.3—Typical Current-Force Diagram for Three-Phase Frequency-Converter Type Machines

404.3 Setup Procedure for Electrostatic (Condenser Discharge) Stored-Energy Machines (Supplementing Table 4.6)

- (a) Insert the electrodes of recommended size and contour for the thickness combination to be welded and provide recommended electrode force.
- (b) Check the force at the electrodes for magnitude and consistency with a force gage.
- (c) Adjust the capacitor bank to provide the recommended mfd capacity and the transformer to provide the recommended turns ratio.
- (d) If forging is to be used (none of the schedules in Table 4.6 call for it), the current-force relationship must be adjusted by means of the forge delay time to provide forging at the correct time. Fig. 4.4 shows a typical current-force diagram for electrostatic stored-energy machines. Refer to text on Welding Force (Par. 405.3) for details.
- (e) The charging voltages shown, which directly affect the welding current, are approximate and intended to be a guide. To obtain the required current by charging voltage adjustment, simply start with a low value of charging voltage, and make and test single-spot shear specimens, increasing the charging voltage until the desired shear strength, weld diameter and penetration are obtained.
- (f) Check the machine for consistency of operation by making and testing 20 single-spot shear specimens for macroscopic examination.
- (g) A variation of $\pm 12\frac{1}{2}\%$ in 90% of the specimens and $\pm 25\%$ in the balance is considered good.
- (h) The machine settings obtained constitute an individual machine schedule and should be recorded for future reference.
- (i) The average weld strength and fused zone diameters shown indicate what may be obtained for definite conditions of surface preparation, fit-up and other factors. However, consistent welds exceeding minimum

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Table 4.5—Spot Welding Magnesium Alloys on Electrostatic (Condenser Discharge) Stored-Energy Type Machines

ASTM ALLOY DESIG- NATION	MATERIAL THICKNESS (see note 1)	ELECTRODE DIAMETER AND SHAPE (see note 2)	NET ELECTRODE FORCE	CAPACIT- TANCE	CHARGING VOLTAGE (see note 3)	TRANS- FORMER TURNS	MINIMUM CONTACTING OVERLAP (see note 4)	MINIMUM WELD SPACING (see note 5)	DIAMETER OF FUSED ZONE	MINIMUM AVERAGE SHEAR STRENGTH
	IN.	D, IN.	R, IN.	LB	FTD	KV	RATIO	IN.	IN.	LB
AZ31B	0.016	1/2	2	650	240	1.4	480:1	1/4	0.10	140
AZ31B	0.020	1/2	3	700	240	1.6	480:1	1/4	0.14	175
AZ31B	0.025	1/2	3	750	360	1.8	480:1	1/4	0.16	215
AZ31B	0.032	1/2	3	850	480	2.0	480:1	5/16	0.18	270
AZ31B	0.040	1/2	3	1,000	720	2.2	480:1	3/8	0.20	345
AZ31B	0.050	5/8	4	1,300	840	2.2	480:1	7/16	0.23	490
AZ31B	0.063	5/8	4	1,650	1,080	2.2	480:1	1/2	0.27	545
AZ31B	0.071	5/8	4	1,900	1,320	2.2	480:1	9/16	0.29	610
AZ31B	0.080	5/8	4	2,200	1,640	2.2	480:1	5/8	0.31	690
AZ31B	0.090	3/4	4	2,550	1,860	2.2	480:1	3/4	0.32	770
AZ31B	0.100	3/4	6	2,950	1,980	2.2	480:1	7/8	0.34	865
AZ31B	0.125	7/8	6	4,000	2,280	2.2	480:1	1-1/8	0.38	1,080
AZ61A	0.040	1/2	3	1,000	600	1.7	300:1	3/8	0.19	470
AZ61A	0.125	7/8	6	4,000	2,640	2.4	450:1	1-1/8	0.32	2,290
MA	0.016	3/8	2	300	360	1.8	480:1	1/4	0.08	70
MA	0.020	3/8	3	350	600	2.0	480:1	1/4	0.12	95
MA	0.025	3/8	3	400	720	2.0	480:1	1/4	0.14	130
MA	0.032	3/8	3	500	840	2.0	480:1	5/16	0.16	175
MA	0.040	1/2	3	650	960	2.0	480:1	3/8	0.18	225
MA	0.050	1/2	4	850	1,200	2.0	480:1	7/16	0.21	295
MA	0.063	5/8	4	1,150	1,440	2.0	480:1	1/2	0.24	385
MA	0.071	5/8	4	1,400	1,680	2.0	480:1	9/16	0.26	430
MA	0.080	5/8	4	1,650	1,800	2.0	480:1	5/8	0.28	495
MA	0.090	5/8	4	1,900	2,040	2.0	480:1	3/4	0.29	560
MA	0.100	3/4	6	2,200	2,160	2.0	480:1	7/8	0.31	630
MA	0.125	3/4	6	3,000	2,640	2.4	480:1	1-1/8	0.35	800

- NOTES:
1. Thickness of one member of a like-thickness two-member assembly.
 2. Where practical a spherical radius is recommended. This radius should be the same on both the top and bottom electrodes for like thicknesses and material combinations unless the contour of the part is such that unlike radii are necessary to effect a heat balance.
 3. Refer to step (5) of the "Set-Up Procedure for Electrostatic (Condenser Discharge) Stored Energy Machines" which supplements this Table.
 4. Avoid using contacting overlaps below the value specified, otherwise weld strengths will be difficult to maintain under shop conditions or distortion of the lapping sheets may occur.
 5. Minimum weld spacing that will require no special precautions to be taken to compensate for shunted current effect of an adjacent weld.

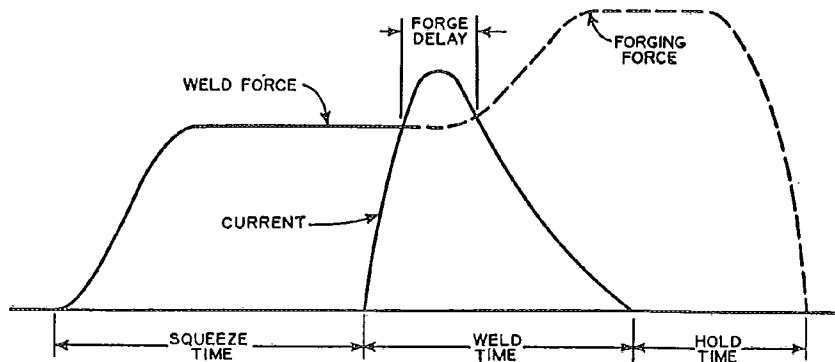


Fig. 4.4—Typical Current-Force Diagram for Electrostatic Stored-Energy Type Machines

shear requirements are satisfactory.

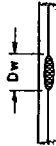
404.4 Setup Procedure for Single-Phase A-C Machines (Supplementing Table 4.7)

- (a) Insert electrodes of recommended size and contour for the thickness combination to be welded and provide recommended electrode force.
- (b) Check the force at the electrode for magnitude and consistency with a force gage.
- (c) Adjust the control to obtain the recommended approximate weld time.
- (d) The welding currents shown are approximate and intended to be a guide or starting point. Welding currents may be measured accurately by primary or secondary measurement methods. The magnitude or recommended welding current is usually obtained by transformer tap settings or phase-shift heat control or both. Weld nugget diameters and minimum consistent strength will be obtained if the current is controlled to $\pm 5\%$ of recommended welding currents in Table 4.7. Figure 4.5 shows a typical current-force diagram for single phase a-c machines.
- (e) Check the machine for consistency of operation and make and test 20 single-spot shear specimens and 5 specimens for macroscopic examination. A variation of $\pm 12\frac{1}{2}\%$ in 90% of the specimens and $\pm 25\%$ in the balance is considered good.
- (f) The machine settings obtained constitute an individual machine schedule and should be recorded for future reference.
- (g) The average weld strength shown indicates what may be obtained for definite conditions of surface preparation, setup and other factors. However, consistent welds exceeding minimum strength requirements are satisfactory.

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Table 4.7—Spot Welding Magnesium Alloys on Single-Phase AC Type Machines

ASTM ALLOY DESIG- NATION	MATERIAL THICKNESS (see note 1)	ELECTRODE DIAMETER AND SHAPE (see note 2)		NET ELECTRODE FORCE		WELD TIME APPROX. (see note 3)	WELDING CURRENT APPROX. (see note 4)	MINIMUM CONTACTING OVERLAP (see note 4)	MINIMUM WELD SPACING (see note 5)	DIAMETER OF FUSED ZONE 	MINIMUM AVERAGE SHEAR STRENGTH
		D, IN.	R, IN.	WELD FORCE LB	LE						
AZ31B	0.016	3/8	2	300	None	2	16,000	3/8	1/4	0.10	160
AZ31B	0.020	3/8	3	350	None	3	18,000	7/16	1/4	0.14	175
AZ31B	0.025	3/8	3	400	None	3	22,000	7/16	1/4	0.16	215
AZ31B	0.032	3/8	3	450	None	4	24,000	1/2	5/16	0.18	270
AZ31B	0.040	1/2	3	500	None	5	26,000	9/16	3/8	0.20	345
AZ31B	0.050	1/2	4	550	None	5	29,000	5/8	7/16	0.23	430
AZ31B	0.063	1/2	4	600	None	6	31,000	3/4	1/2	0.27	545
AZ31B	0.071	1/2	4	650	None	7	32,000	13/16	9/16	0.29	610
AZ31B	0.080	1/2	4	700	None	8	33,000	7/8	5/8	0.31	690
AZ31B	0.090	1/2	4	750	None	9	34,000	15/16	3/4	0.32	770
AZ31B	0.100	1/2	6	800	None	10	36,000	1	7/8	0.34	865
AZ31B	0.125	1/2	6	1,000	None	12	42,000	1-1/8	15/16	0.38	1,080
MIA	0.016	3/8	2	300	None	3	17,000	3/8	1/4	0.08	70
MIA	0.020	3/8	3	300	None	3	20,000	7/16	1/4	0.12	95
MIA	0.025	3/8	3	350	None	4	24,000	7/16	1/4	0.14	130
MIA	0.032	3/8	3	400	None	5	26,000	1/2	5/16	0.16	175
MIA	0.040	1/2	3	450	None	6	28,000	9/16	3/8	0.18	225
MIA	0.050	1/2	4	500	None	7	30,000	5/8	7/16	0.21	295
MIA	0.060	1/2	4	550	None	8	32,000	3/4	1/2	0.24	385
MIA	0.071	1/2	4	600	None	9	33,000	13/16	9/16	0.26	430
MIA	0.080	1/2	4	650	None	10	35,000	7/8	5/8	0.28	495
MIA	0.090	1/2	4	700	None	11	36,000	15/16	3/4	0.29	560
MIA	0.100	1/2	6	750	None	12	38,000	1	7/8	0.31	630
MIA	0.125	1/2	6	950	None	14	45,000	1-1/8	15/16	0.35	800

NOTES:

- Thickness of one member of a like-thickness two-member assembly.
- Where practical a spherical radius is recommended. This radius should be the same on both the top and bottom electrodes for like thicknesses and material combinations unless the contour of the part is such that unlike radii are necessary to effect a heat balance.
- Refer to step (4) of the "Set-up Procedure for Single-Phase A.C. Machines" which supplements this Table.
- Avoid using contacting overlaps below the value specified, otherwise weld strengths will be difficult to maintain under shop conditions or distortion of the lapping sheets may occur.
- Minimum weld spacing that will require no special precautions to be taken to compensate for shunted current effect of an adjacent weld.

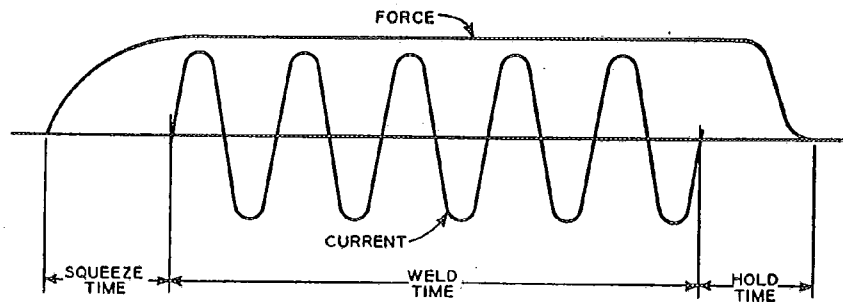
Recommended Practice for

Fig. 4.5—Typical Current-Force Diagram for Standard Single-Phase AC Type Machines

404.5 Set up Procedure for Three-Phase Dry-Disc Rectifier Machines
Supplementing Table 4.8)

- (a) Insert electrodes of recommended size and contour for the thickness combination to be welded and provide recommended electrode force.
- (b) Check the force at the electrodes for magnitude and consistency with a force gage.
- (c) Adjust the control to obtain the recommended approximate weld and postheat times.
- (d) On thicknesses requiring forging, the current-force relationship must be adjusted by means of the forge delay time to provide forging at the correct time. Figure 4.6 shows a typical current-force diagram for three-phase rectifier machines. Refer to text on Welding Force for detailed information.
- (e) The welding currents, weld and postheat, shown are approximate and intended to be a guide. To obtain the required current, simply start with a low value, and make and test single-spot shear specimens, increasing the current until the desired shear strength, weld diameter and

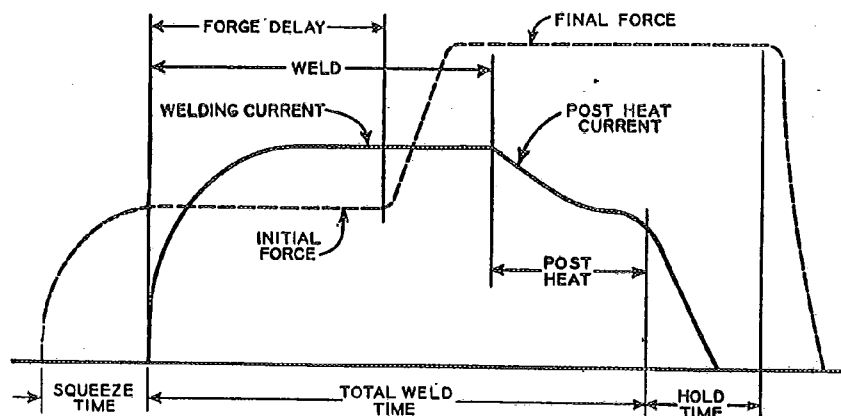


Fig. 4.6—Typical Current-Force Diagram for Three-Phase Dry-Disc Rectifier Type Machine

Spot Welding Magnesium Alloys

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Table 4.8—Spot Welding Magnesium Alloys on Three-Phase Dry-Disc Rectifier Type Machines

ASTM ALLOY DESIGN- ATION	MATERIAL THICKNESS (see note 1)	ELECTRODE DIAMETER AND SHAPE (see note 2)	NET ELECTRODE FORCE		FORGE DELAY TIME	WELD TIME	CYCLES (60/SEC)	POST- HEAT TIME	WELDING CURRENT APPROX.		MINIMUM CONTACTING OVERLAP (see note 4)	MINIMUM WELD SPACING (see note 3)	DIAMETER OF FUSED ZONE	MINIMUM AVERAGE SHEAR STRENGTH
			LB	IN.					WELD	POSTHEAT				
	IN.	D, IN.	LB	IN.	CYCLES (60/SEC)	CYCLES (60/SEC)	CYCLES (60/SEC)		AMP	AMP	IN.	CENTER TO CENTER IN.	IN.	LB
AZ31B	0.020	5/8	300	3	0.6	1	1	1	21,000	14,700	7/16	1/4	0.14	145
AZ31B	0.032	5/8	400	3	1.0	2	1	1	24,000	16,900	1/2	5/16	0.18	245
AZ31B	0.040	5/8	480	3	1.0	2	2	2	26,000	18,000	9/16	3/8	0.20	336
AZ31B	0.051	5/8	580	3	1.5	3	2	2	28,500	20,000	5/8	7/16	0.22	435
AZ31B	0.064	5/8	700	4	1.8	3	3	3	29,300	20,500	3/4	1/2	0.27	560
AZ31B	0.081	7/8	860	4	2.4	4	4	4	35,750	25,000	7/8	5/8	0.31	740
AZ31B	0.093	7/8	970	6	3.9	6	4	4	38,750	27,100	15/16	3/4	0.32	855
AZ31B	0.102	7/8	1,050	6	4.5	7	4	4	41,300	28,800	1	7/8	0.34	985
AZ31B	0.125	7/8	1,270	6	7.7	10	6	6	48,000	33,400	1-1/8	15/16	0.38	1,208
AZ31B	.020-.025	5/8	300	3	0.9	1	1	1	24,000	16,500	7/16	1/4	0.16	167
AZ31B	.020-.040	5/8	300	3	1.4	2	1	1	23,700	16,500	7/16	1/4	0.19	285
AZ31B	.020-.051	5/8	300	3	1.0	1	1	1	25,600	17,500	7/16	1/4	0.17	228

NOTE:

1. Thickness of one member of a like-thickness two-member assembly, except where indicated.
2. Where practical a spherical radius is recommended. This radius should be the same on both top and bottom electrodes for like thickness and material combinations unless the contour of the part is such that unlike radii are necessary to effect a heat balance.
3. Minimum weld spacing that will require no special precautions to be taken for shunted current effect of an adjacent weld.
4. Avoid using contacting overlaps below the value specified, otherwise weld strengths will be difficult to maintain under shop conditions, or distortion of the lapping sheets may occur.

penetration are obtained.

(f) Check the machine for consistency of operation by making and testing 20 single-spot shear specimens and 5 specimens for macroscopic examination.

(g) A variation of $\pm 12\frac{1}{2}\%$ in 90% of the specimens and $\pm 25\%$ in the balance is considered good.

(h) The machine settings obtained constitute an individual machine schedule and should be recorded for future reference.

(i) The average weld strength and fused zone diameters shown indicate what may be obtained for definite conditions of surface preparation, fit-up and other factors. However, consistent welds exceeding minimum strength requirements are satisfactory.

405. WELDING TECHNIQUE

405.1 Welding Dissimilar Magnesium Alloys and Thicknesses

Differences in thermal conductivity and electrical resistivity must be taken into account when attempting to weld dissimilar wrought magnesium alloys if a balanced weld nugget is to be obtained. As shown in Table 4.9, alloys having low electrical resistivity generally have high thermal conductivity and vice versa. This means that alloys falling into the latter group will require less heat (weld current) to generate a given size weld nugget than do those alloys belonging to the former group. As a consequence when welds are made between alloys belonging to these two extreme groups it is necessary to produce a heat balance by placing a smaller electrode tip (increased current density) against the alloy having the lowest resistance so as to obtain a balanced weld nugget. It may also be necessary to use an electrode with a facing of high thermal resistance against the alloy with the lowest resistivity to aid in effecting a balanced nugget. In the case of dissimilar thicknesses of dissimilar alloys, the alloy with the lowest resistivity can be determined by multiplying the material thickness by its electrical resistivity. In the case of unequal thicknesses of the same alloy an electrode with a larger contact area should be used against the thicker material to aid in producing a balanced weld nugget.

Machine schedules for dissimilar material thicknesses should be based on those required for the thinnest sheet. For maximum consistency and high weld strengths the ratio of metal thicknesses should not exceed $2\frac{1}{2}$ to 1. In three thickness "pile-ups" the thickness variation among members should not exceed 25% and the thickest member of the pile-up should be in the center of the stack.

405.2 Machine Adjustment

The product to be welded and the quality and size of weld desired determine the operational limits for current, pressure and time. For given conditions there are optimum values of welding force, welding time and

Table 4.9—Physical Properties of Importance in Resistance Welding Wrought Magnesium Alloys

ASTM alloy designation	Approximate* solidification range, F deg	Thermal conductivity** CGS units	Electrical resistivity** microhm-centimeters
AZ31B-H24	1050-1160	0.18	9.2
AZ61A-F	950-1137	0.14	12.5
AZ80A-T5	900-1115	0.14	12.2
HK31A-H24	1092-1195	0.27	6.1
HM21A-T8	1121-1202	0.33	5.0
HM31A-T5	1121-1202	0.25	6.6
MIA-F	1198-1202	0.31	5.4
ZE10A-H24	1100-1195	0.31	5.2
ZK21A-F	—	0.30	5.4
ZK60A-T5	970-1175	0.29	5.7

*Solidus to liquidus temperature. C=5/9 (F-32)

**At 20C, or 68F

welding current. A comprehensive understanding of these variables is desirable.

405.3 Welding Force

The electrode force holds the various interfaces in intimate contact during the welding cycle. It must be sufficient to localize the area of current flow, reduce resistance between electrodes and sheet surfaces and minimize weld defects. In general, the low-strength alloys require lower electrode force than the high-strength alloys.

Insufficient force is characterized by weld metal expulsion, internal defects, surface burning and excessive tip pickup and necessitates the use of lower welding currents since higher contact resistance is developed at the faying surface. Excessive force is characterized by extreme indentation, sheet separation, work distortion and unsymmetrical welds and necessitates the use of higher welding current since low contact resistance is developed at the faying surface. The use of electrode force in the welding cycle is further affected by the application of forging or increased electrode force at the correct instant in the formation of the weld.

The variable force cycle, in which the weld is made at low force, followed by the application of a higher force, is used to provide squeezing action during the solidification period. Timing of the application of the forging force is extremely important since its purpose is to reduce internal defects. If the forging force is applied too late the weld will have solidified

and the extra force will not have accomplished its purpose. If the forging force is applied too soon the welding current may be insufficient for the higher force, resulting in weak or unsound welds. The correct timing for the forging application may be determined by a recording oscilloscope and supplementary specimens.

The resistance welding of magnesium requires careful consideration of electrode force, welding current and welding time. Because of the relatively high thermal and electrical conductivities of magnesium alloys, high currents and short weld durations are required in spot welding. Rapid follow-up of the electrodes is also required to maintain pressure on the weld while the metal is in the plastic range. This rapid response to changes in applied force is generally accomplished by means of a low inertia head, antifriction bearings on the ram assembly and some form of pressure application mechanism which avoids air cylinder piston friction.

The applied force cycle of predetermined magnitude, duration and relationship to the thermal cycle must be accurately reproduced for resistance welding of magnesium.

When pressure is applied to the material by the electrodes a small interface area has intimate contact. As current is applied and the weld nugget forms, a pressure ring is produced around the nugget at the interface. This pressure ring is usually from 1/32 to 1/16 in. larger in diameter than the nugget and increases as the nugget increases in size. If the pressure ring is too narrow, it is unable to contain the molten weld puddle as it expands and spitting occurs at the interface. A narrow pressure ring is usually caused by electrodes with too sharp a tip contour or by applying the weld current so rapidly that pressure follow-up is inadequate. The decrease in the volume of the weld metal as it solidifies is one of the causes of shrinkage cracks in the weld nugget. Sound welds are produced by reducing the shrinkage stresses in the nugget through the application of sufficient electrode pressure.

405.4 Welding Time

Weld time is considered to be the actual time during which the welding or secondary current flows. The duration of current flow must be sufficient to effect the weld without excessively heating the surrounding metal. Short times are generally desirable for magnesium. Since the thermal conductivity of magnesium is high, the flow of current for long durations causes the surrounding metal to heat excessively. The rate of current rise and decay is, therefore, an important factor and in the case of stored-energy machines determines the weld time duration. Heavy gage materials require weld times of longer duration than light gages. The rate of current rise affects important weld factors such as strength, consistency, structure, heat-affected zone and appearance. Since short time is desired, the faster the rate of current rise within limits, the shorter the weld times. However, excessively high rates of current rise, causing an extremely steep temperature gradient between the surface and the weld, result in porous and cracked welds and weld expulsion.

The duration of weld time is adjusted on single phase a-c machines by the number of cycles used, on three-phase frequency-converter machines by the number of pulses used, and on stored-energy machines by altering the wave form through changes in inductance, capacitance and voltage. The strength of a weld, within narrow limits, is proportional to the weld time. Beyond these limits, longer weld times produce no appreciable increase in weld strength.

405.5 Welding Current

The electric current flowing for a given time provides the energy to produce the desired weld, and like aluminum, higher currents are required for magnesium than most other materials. Variations in weld strength may be accomplished by simply varying the welding current. Up to a point, weld strength increases with increase in current, beyond this it may be necessary to increase electrode size and force.

The current may be determined by selecting the optimum force, time and electrodes and simply increasing the current from a low value, until the desired weld strength is obtained. Since the energy developed varies as the square of the current, the heat generated increases rapidly with current increase. Use of excessively low current results in inconsistent and low strength welds, whereas use of high currents results in cracks, porosity, and weld expulsion. The welding current on a-c machines may be varied by transformer taps or phase shifting, and on stored-energy machines by altering the wave form. For example, on capacitor stored-energy machines the welding current may be increased by addition of capacitance in the circuit, or by increasing the charging voltage (see Fig. 4.7).

High welding current, considerably greater than necessary for steel,

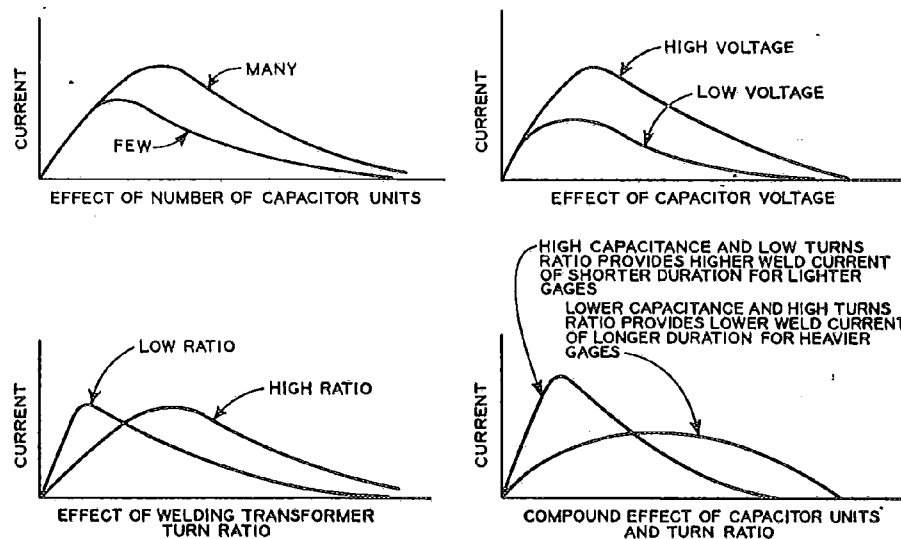


Fig. 4.7—Wave Shape of Electrostatic Equipment

is required for magnesium because of its relatively high electrical and thermal conductivities.

405.6 Electrodes

405.6.1 MATERIAL

Electrodes for spot welding magnesium should be of high conductivity copper alloys conforming to RWMA, Group A, Class 1 or 2 specification. Hard-rolled pure copper is used where special offset electrodes are desired.

RWMA Group A, Class 1 electrodes are non-heat treatable, wrought materials which receive their mechanical properties by cold reduction. If an electrode having higher mechanical properties is needed, the alloy classified as RWMA Group A, Class 2 may be used. This is a heat treatable alloy used in cast or wrought form. Its electrical and thermal conductivity are somewhat lower than that of the Class 1 alloy.

405.6.2 DIAMETER

The recommended electrode diameter for respective gage combinations are indicated in the welding schedules (see Section 404).

405.6.3 SHAPE

The electrode contour determines to a large extent the size and shape of the weld and to some degree the exterior sheet appearance. Dome-ended tips are most common with tip radii ranging from 2 to 8 in. depending upon sheet thickness.

405.6.4 MAINTENANCE

In order to maintain electrode contour and minimize contact resistance between the work and the electrode, frequent cleaning of the electrodes is necessary. Table 4.1 indicates the approximate number of welds which can be made on several magnesium alloys when using mechanical or chemical cleaning of the base metal. Maximum tip life is obtained with chemically cleaned surfaces when using RWMA Group A Class 1 electrodes.

It is recommended that indiscriminate manual use of abrasives to clean tips should be supplanted by cleaning the tip with an electrode dressing tool such as shown in Fig. 4.8. Abrasive paper of about 280 grit may be wound about the paddle's working surface which has the proper contour machined in it. The cleaning paddle should not be wrapped with excessive layers of emery cloth as this destroys the accuracy of the radius. Usually two layers suffice, and in thinner gages where a very accurate radius is to be maintained, not more than one layer should be used.

405.6.5 ELECTRODE COOLING

Electrode cooling is an important factor in pickup although cooling to excessively low temperatures may have a harmful effect on pickup. Electrodes should be water cooled to within $\frac{3}{8}$ in. of the tip, but should never be cooled below the dew point. When low temperatures are used, condensation takes place on the tip, materially increasing the electrode-to-sheet resistance during welding, and consequently pickup or burning takes place more rapidly. Water cooling greatly improves tip life and should always be used. Better tip life is obtained when small or medium sized welds rather than large welds requiring high currents are produced.

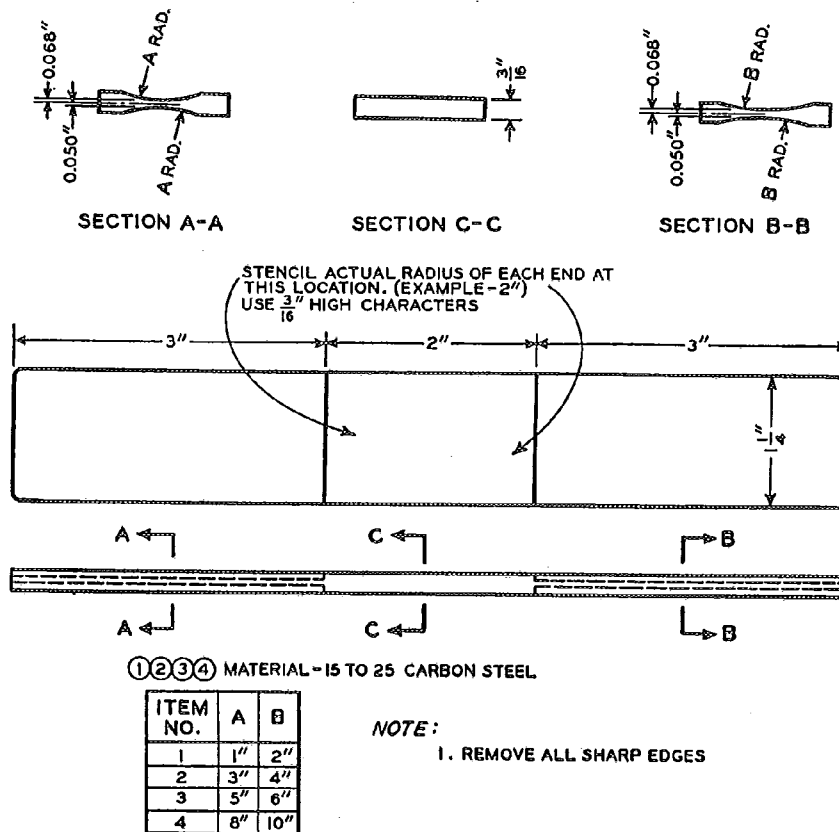


Fig. 4.8—Electrode Dressing Tool—Double

406. WELDING DEFECTS AND CAUSES

406.1 External Defects

406.1.1 EXCESSIVE INDENTATION

Excessive indentation appears as a deep depression of the weld surface (see Fig. 4.9). Some indentation is unavoidable since vertical expansion of the weld metal is immediately forged out by the pressure of the electrodes. The limits of acceptability generally range from 10 to 20 percent of sheet thickness in which the indentation occurs. Deep in-

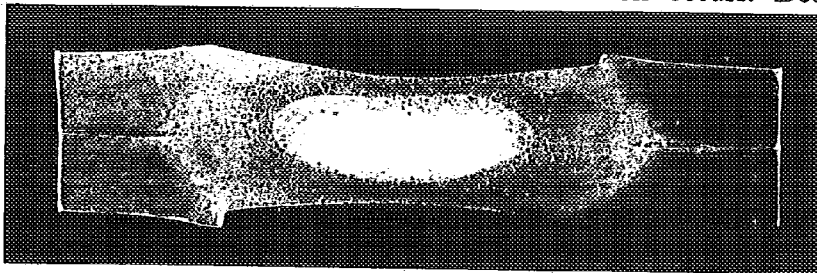


Fig. 4.9—Excessive Indentation (6X magnification; acetic-picral etchant)

dentation results in a loss of strength due to a reduction of metal thickness at the periphery of the weld. Excessive indentation may be caused by one or more of the following factors:

- Too small electrode tip contour
- Excessive welding force
- Excessive welding current
- Expulsion
- Excessive penetration
- Excessive surface heating
- Improper forging cycle

406.1.2 DISTORTION

Distortion or edge bulge is a condition that occurs when welds are placed too near a metal edge (see Fig. 4.10). The edge distance must be great enough to provide adequate strength to resist deformation and



Fig. 4.10—Surface Distortion Resulting in Edge Cracking (2X magnification)

conduct heat to reduce edge cracking. Surface distortion may be caused by one or more of the following factors:

- Electrode skidding
- Excessive welding force
- Insufficient edge distance
- Improper fit-up of parts
- Expulsion
- Excessive welding current

406.1.3 SHEET SEPARATION

Sheet separation is defined as the parting of the faying surfaces adjacent to the weld area (see Fig. 4.11). Separation is normally acceptable for primary or secondary structural applications when not in excess of 10 percent of the average thickness of the two outer sheets. Excessive separation is an undesirable condition because it increases the bending moment on the joint when stressed in shear. Sheet separation may be

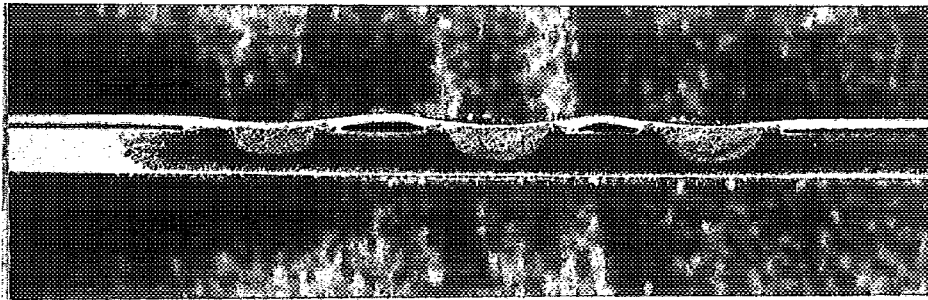


Fig. 4.11—Excessive Sheet Separation (2.25X magnification; 10% acetic acid etchant)

caused by one or more of the following factors:

- Excessive welding force
- Electrode misalignment
- Too small electrode tip contour
- Expulsion
- Excessive welding current
- Improper fit-up of parts
- Excessive welding time

406.1.4 EXPULSION

Expulsion, a condition generally caused by excessive heat and improper force, may be defined as the ejection of molten metal from the weld zone (see Fig. 4.12). To avoid expulsion, the electrode force and contour must be sufficient to provide a pressure seal around the weld and the faying surface must be free of contamination. Weld expulsion is normally accompanied by deep surface indentation, sheet separation, voids and loss of weld strength. Expulsion may be caused by one or more of the following factors:

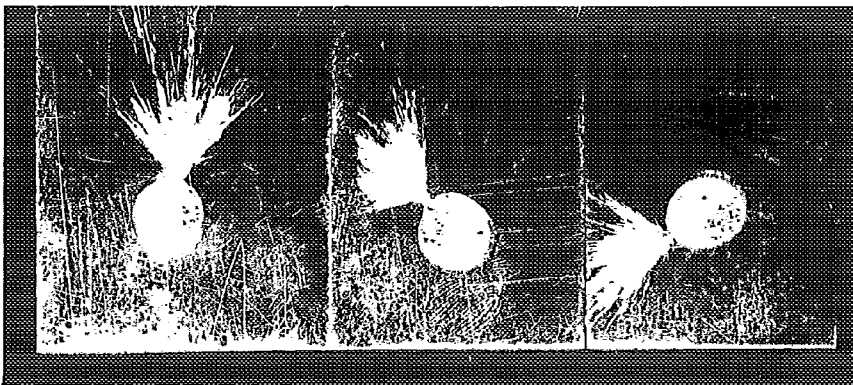


Fig. 4.12—Expulsion Between Faying Surfaces (0.8X magnification)

- Improper surface condition
- Insufficient welding force
- Excessive welding current
- Too small electrode tip contour
- Electrode misalignment
- Electrode skidding

406.1.5 COPPER PICKUP

Copper pickup increases the corrosion susceptibility of the spot weld. Copper deposits may be completely removed with steel wool, by wire brushing or sanding the affected area. To test for complete removal apply a 10 percent acetic acid solution to the weld; deposits of copper will turn black (see Fig. 4.13). Tip pickup may be caused by one or more of

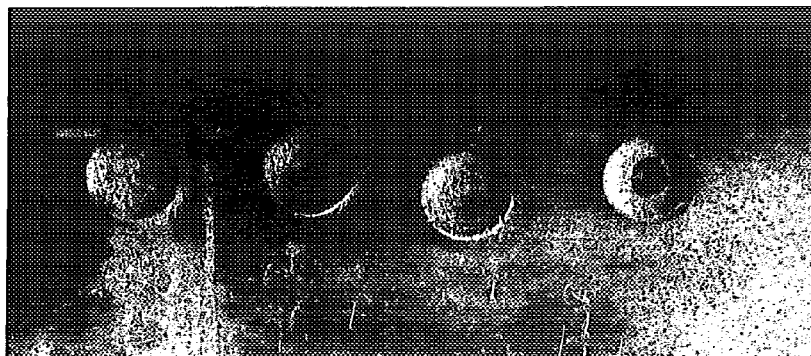


Fig. 4.13—Copper Pickup (1.5X magnification)

the following factors:

- Improper choice of surface preparation (see Table 4.1)
- Too infrequent electrode cleaning
- Condensation (moisture) on electrode tips
- Excessive welding current
- Insufficient welding force

406.1.6 SURFACE FUSION

Surface fusion or burning may be described as the melting of the metal surface in contact with the electrodes (see Fig. 4.14). Weld quality and appearance are adversely affected when surface fusion and burning persist. Surface fusion may be caused by one or more of the following factors:

- Too infrequent electrode cleaning
- Improper surface condition
- Insufficient welding force
- Excessive welding current
- Improper fit-up of parts
- Improper weld sequence timing

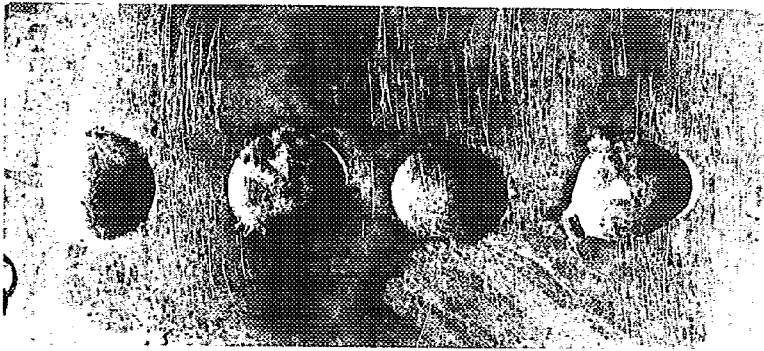


Fig. 4.14—Surface Fusion (1.5X magnification)

Electrode skidding
 Insufficient electrode cooling
 Improper electrode material (conductivity too low)

406.1.7 EXTERNAL CRACKS

Cracks extending to the surface of a spot weld (see Fig. 4.15) normally indicate an improper force and current relationship. The welding force must be great enough to prevent excessive heat generation (low welding forces cause high contact resistance) and applied long enough to properly quench the fused area. Surface cracking lowers the corrosion resistance of spot welds. Under certain conditions the strength of the spot weld will be decreased if surface cracking is extensive. External cracks may be caused by one or more of the following factors:

Improper weld sequence timing
 Electrode misalignment
 Improper fit-up of parts
 Insufficient welding force
 Excessive penetration
 Excessive welding current
 Insufficient electrode cooling

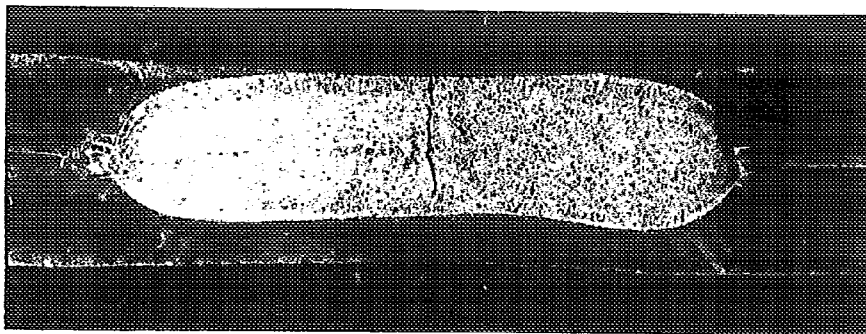


Fig. 4.15—External Crack (7.5X magnification; acetic-picral etchant)

406.2 Internal Defects**406.2.1 INCONSISTENCY**

Consistent high quality spot welds require rigid control of thickness, composition, surface condition and temper of the materials being welded; the electrical-mechanical relationship of the equipment; electrode maintenance; the choice of welding schedule. Internal integrity is often difficult to determine short of destructive testing; therefore, assurance methods must be employed to reduce the possibility of weld failure. Consistency may be defined as the ability to produce welds of sufficient strength, free of defects.

406.2.2 SYMMETRY

A well-formed nugget may be defined as being symmetrical to both the horizontal and vertical axes (see Fig. 4.16). To obtain consistent weld

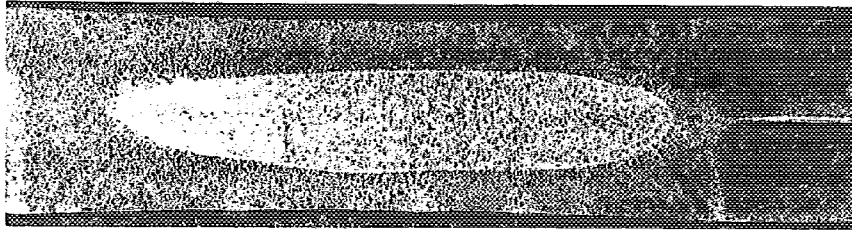


Fig. 4.16—Typical Weld Penetration (7.5X magnification; acetic-picral etchant)

quality it is desirable to have uniformly shaped nuggets, properly located and aligned in the joint. Welds in Fig. 4.17 represent poorly formed nuggets. Unsymmetrical welds may be caused by one or more of the

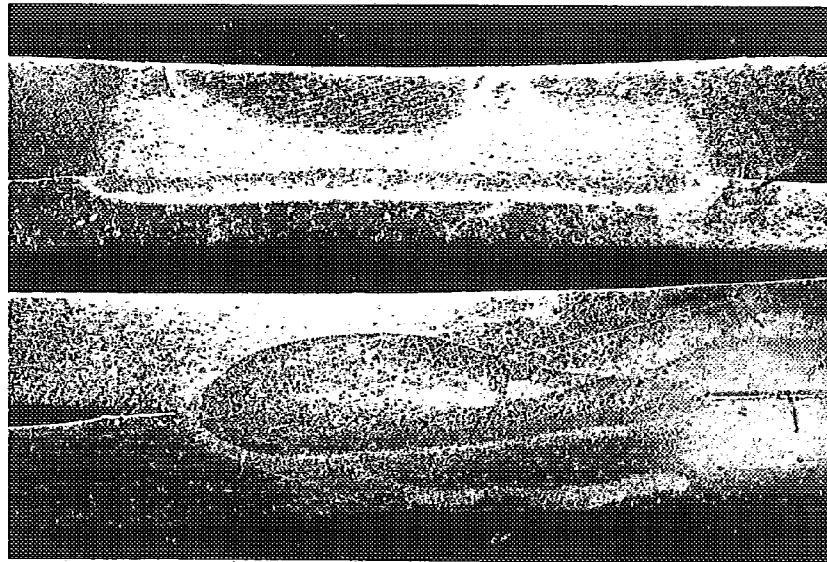


Fig. 4.17—Unsymmetrical Welds (8X magnification; 10% acetic acid etchant)

following factors:

- Electrode misalignment
- Too small electrode tip contour
- Improper surface condition
- Improper weld schedule
- Improper fit-up of parts

406.2.3 WELD PENETRATION

Penetration in a spot weld may be defined as the depth to which fusion extends into the member in which it occurs; it is expressed as a percentage of the thickness of the sheet. The limit of penetration is ordinarily permitted to vary from 20 to 80 percent. Welds exceeding the minimum or maximum limits may result in an undesirable change in weld strength.

(a) *Insufficient Penetration*—Welds produced with less than 20 percent penetration could result in some complete failures due to normal variations in current, time, and electrode force (see Fig. 4.18). In-

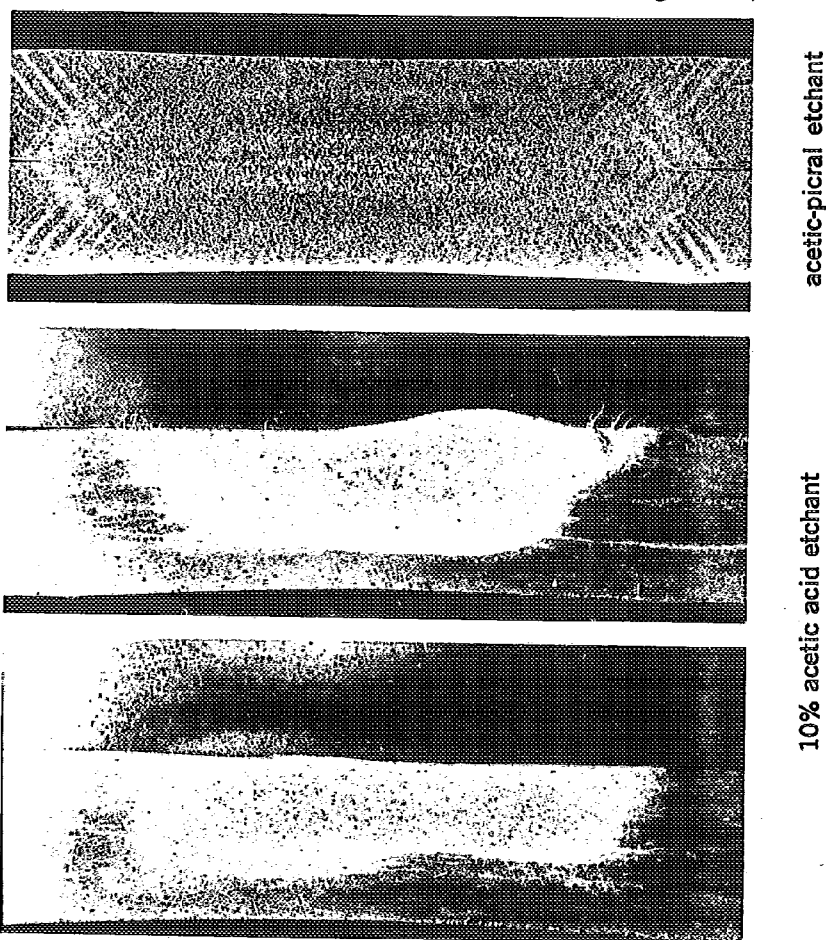
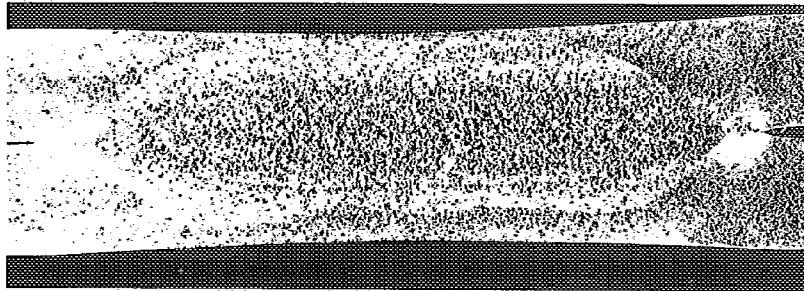


Fig. 4.18—Insufficient Weld Penetration (7.5X magnification)

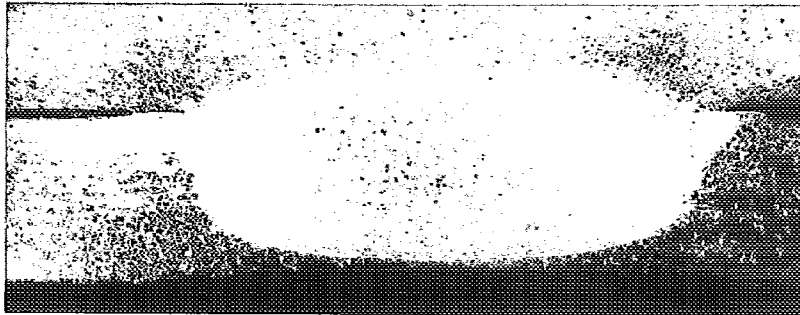
sufficient penetration may be caused by one or more of the following factors:

- Insufficient welding current
- Excessive welding force
- Improper heat balance
- Too large electrode tip contour
- Insufficient welding time
- Improper surface condition

(b) *Excessive Penetration* — Welds with more than 80 percent penetration may create other defects such as expulsion, tip pickup, cracks, and porosity with normal variations of current, time, and electrode force (see Fig. 4.19). Excessive penetration may be caused by one or



acetic-picric etchant



10% acetic acid etchant



Fig. 4.19—Excessive Weld Penetration (7.5X magnification)

more of the following factors:

- Improper surface condition
- Too small electrode tip contour
- Excessive welding current
- Improper weld sequence timing
- Insufficient welding force
- Insufficient electrode cooling

406.2.4 VOIDS AND POROSITY

A porous weld structure, as illustrated in Fig. 4.20, is normally a result of an improper application of welding force and current. Voids are

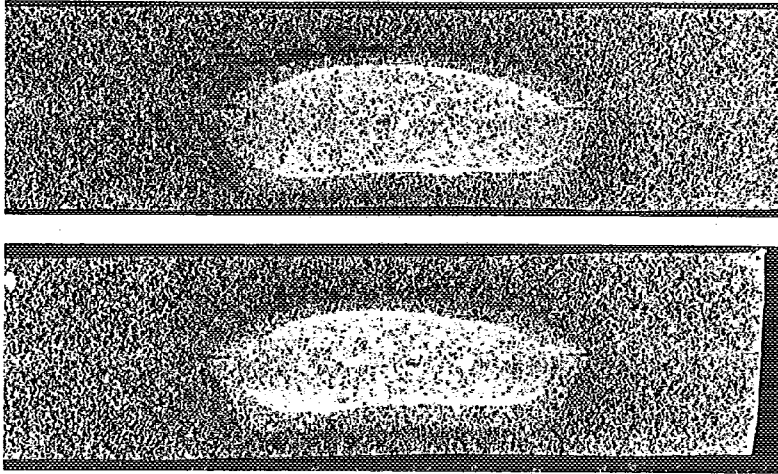


Fig. 4.20—Voids and Porosity (8X magnification; phospho-picral etchant)

generally produced when severe expulsion occurs. Porosity is normally the result of insufficient force. Voids and porosity may be caused by one or more of the following factors:

- Expulsion
- Improper welding force
- Improper weld sequence timing
- Improper rate of welding current rise
- Insufficient welding time

406.2.5 INTERNAL CRACKS

Internal weld cracking may be detected nondestructively by radiography or destructively by sectioning the weld. The effect of cracks on the service life of the spot weld will not be defined here. Usually, specifications are careful to spell out the degree of weld soundness required in the intended use. Cracks may occur in the transverse or longitudinal direction in a spot weld. They may extend to the heat-affected zone or be confined to the center of the nugget, i.e., shrinkage cracks (see Fig. 4.21). Internal cracks may be caused by one or more of the following factors:

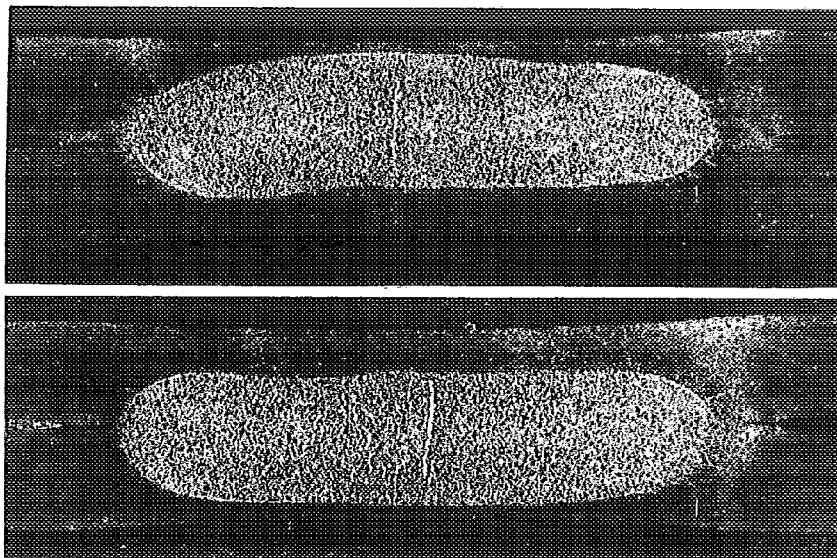


Fig. 4.21—Internal Cracks (7.5X magnification; acetic-picral etchant)

Insufficient welding force
 Improper weld sequence timing
 Electrode misalignment
 Excessive welding current
 Electrode skidding
 Insufficient electrode cooling

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V. STANDARD METHODS FOR TESTING RESISTANCE WELDS

501. GENERAL

The test methods presented here, except for *Test No. 13 — Surface Resistance Measurement*, are not intended for the testing of base metal. The base metal to be used will be determined, in each case, by the required material specification. Most of these recommended tests for checking the quality of resistance welds are in common use. Spot, roll spot, seam and projection welds are covered for all ferrous and non-ferrous alloys, where applicable, as indicated in Section 502. Certain limitations are also indicated in Section 504 where the test methods are described. For flash welds, the wide variation possible in size, joint geometry and other factors dictates a more general approach; i.e., tests are listed in Section 502, but selection of appropriate tests and preparation of test specimens may depend upon particular conditions. Drawings or specifications utilizing the test methods presented here should specify the type or types of test and the acceptable limits, as this will depend upon the design of the fabricated parts.

*Single Spot Welds.**—The tests given herein have been written on the basis of single spot welds, but are applicable to the other methods of resistance welding as shown.

*Roll Spot Welds.**—Roll spot welds are to be treated the same as single spot welds, the sample to be prepared as a multiple and cut into the specimens recommended for spot welds.

*Seam Welding.**—Seam welding is an extension of the spot-welding principle to a condition where the spots overlap providing a continuous weld.

*Projection Welds.**—Tests as established for spot welds also apply to projection welds, the projections being made in the sample strip at the point shown for the spot location.

Flash Welds—Selection of the appropriate test methods for flash welds will depend on joint design and other factors. Actual joint conditions will also determine how flash weld test specimens for Tests No. 5, 7 and 9 may be prepared.

502. TYPES OF TEST

The following types of test are recommended for determining the characteristics of resistance welds. In all cases the size of weld (or projection

* Where it is desired to test roll spot welds, seam welds or projection welds which are spaced closer together than will permit using the standard single spot specimen, a specimen of the same width as the standard should be prepared with the welds arranged transversely on the specimen.

in the case of projection welds) depends upon the thickness of material.

Spot Welds

- Test No. 1 Tension-Shear Test
- Test No. 2 Tension Test
 - (a) Cross-Tension Test
 - (b) U-Tension Test
- Test No. 3 Impact Test
 - (a) Shear-Impact Test
 - (b) Drop-Impact Test
 - (c) Shear-Impact Loading Test
 - (d) Tension-Impact Loading Test
- Test No. 4 Fatigue Test
- Test No. 5 Macroetch Test
- Test No. 7 Radiographic Test
- Test No. 8 Torsional Test
- Test No. 9 Hardness Test
- Test No. 10 Peel Test
- Test No. 11 Bend Test (Aluminum & Aluminum Alloys)

Roll Spot Welds

- Test No. 1 Tension-Shear Test
- Test No. 2 Tension Test
 - (a) Cross-Tension Test
 - (b) U-Tension Test
- Test No. 3 Impact Test
 - (a) Shear-Impact Test
 - (b) Drop-Impact Test
 - (c) Shear-Impact Loading Test
 - (d) Tension-Impact Loading Test
- Test No. 4 Fatigue Test
- Test No. 5 Macroetch Test
- Test No. 7 Radiographic Test
- Test No. 8 Torsional Test
- Test No. 9 Hardness Test
- Test No. 10 Peel Test
- Test No. 11 Bend Test (Aluminum & Aluminum Alloys)

Seam Welds

- Test No. 1 Tension-Shear Test
- Test No. 5 Macroetch Test
- Test No. 6 Pillow Test
- Test No. 7 Radiographic Test
- Test No. 9 Hardness Test
- Test No. 11 Bend Test (Aluminum & Aluminum Alloys)
- Test No. 12 Eddy Current Test

Projection Welds

- Test No. 1 Tension-Shear Test
- Test No. 2 Tension Test
 - (a) Cross-Tension Test
 - (b) U-Tension Test
- Test No. 3 Impact Test
 - (a) Shear-Impact Test
 - (b) Drop-Impact Test
 - (c) Shear-Impact Loading Test
 - (d) Tension-Impact Loading Test
- Test No. 4 Fatigue Test
- Test No. 5 Macroetch Test
- Test No. 7 Radiographic Test
- Test No. 8 Torsional Test
- Test No. 9 Hardness Test
- Test No. 10 Peel Test
- Test No. 11 Bend Test (Aluminum & Aluminum Alloys)

Flash Welds

- | | |
|--------------------|-----------------------------|
| Test No. 5 | Macroetch Test |
| Test No. 7 | Radiographic Test |
| Test No. 9 | Hardness Test |
| Tension Test | Refer to ASTM E 8-61T |
| Bend Test | Refer to ASTM E 190-64 |
| Cupping Test | Refer to ASTM A 344-60T |
| Charpy Impact Test | Refer to ASTM E 23-64 |
| Torsion Test | Refer to ASTM (when issued) |

503. PREPARATION FOR TESTING

Consistent test results can be obtained only with careful attention to surface condition. The material should be essentially free of grease, scale or other foreign substances likely to cause a high surface resistance.

The sheared specimen should be essentially flat and free of burrs. Sheared burrs on heavy stock may be sufficient to cause shunting of the current through the edges of the pieces and therefore the burrs should either be removed or the parts placed together with the burrs toward the outside faces of the specimens.

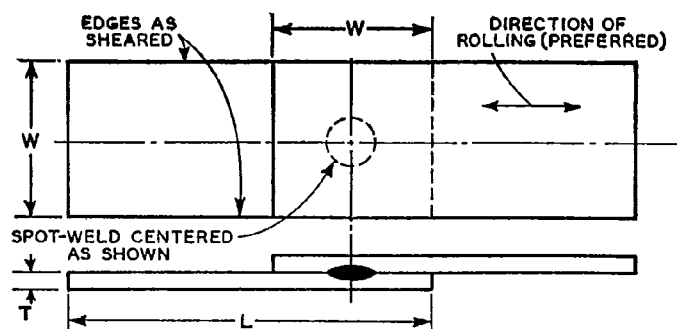
Specimens showing obvious misalignment or lack of centering should be discarded.

504. TEST METHODS**504.1 Tension-Shear Test (Test No. 1)**

This test consists of pulling in tension, to destruction, on a standard testing machine, a test specimen obtained by lapping two strips of metal

and joining them by a single weld. The dimensions of the test specimens are shown in Fig. 5.1.

The ultimate strength of the specimen and the manner of failure, whether by shear of the weld metal, or by tear of the base metal, and whether a ductile or brittle fracture is obtained, should be recorded.



T Thickness of thinner sheet, in.	W Specimen width, in.	L Recommended length, in.
Up to 0.030	$\frac{5}{8}$	3
0.031 to 0.050	$\frac{3}{4}$	3
0.051 to 0.100	1	4
0.101 to 0.130	$1\frac{1}{4}$	5
0.131 to 0.190	$1\frac{1}{2}$	5
0.191 and over	2	6

Fig. 5.1—Tension-Shear Test Specimen

Measurement of the diameter of a weld corresponding to the weld in the tension-shear specimen is desirable. When no other test is contemplated an approximate value of the diameter can be obtained by measurement on the fracture transverse to the direction of pull. More precise measurements can be made with Tests Nos. 2, 3, 5 and 8.

The record of the specimen should also include a complete description of the properties of the metal such as thickness, tensile strength, ductility and chemical composition.

The effect of eccentricity in the use of the above specimens may be disregarded. For specimens 0.101 in. in thickness and over it is recommended that the grips of the testing machine be offset to avoid bending at the grips.

504.2 Tension Test (Test No. 2)

The purpose of the tension test is to provide a better measure of notch sensitivity than is obtained with the tension-shear test. The ratio of the

tensile strength to the tension-shear strength is frequently referred to as the *ductility* of the weld.

The ultimate strength of the weld, the diameter of the weld and the method of fracture should be recorded.

Two types of tension test, (a) *Cross-Tension Test* and (b) *U-Tension Test* are used as described below.

(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 Fig. 5.2 (a) and (b). Special holding jigs are constructed to apply normal tension to the specimens.

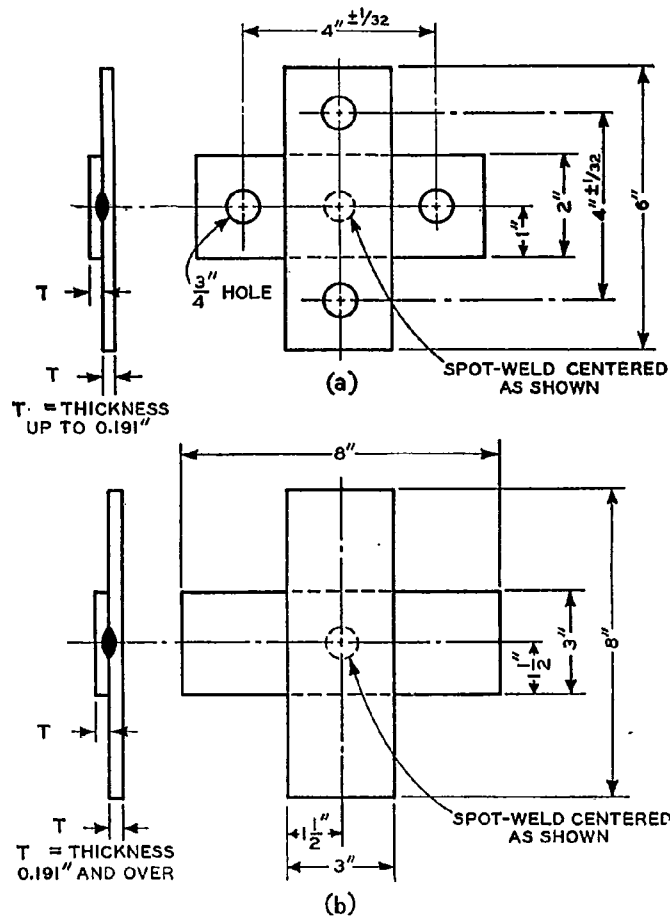


Fig. 5.2—Cross-Tension Test Specimens

The jig for holding the 2 x 6-in. cross specimen of Fig. 5.2 (a), is shown in Fig. 5.3. Various methods of holding the jig in the testing machine may be used such as pin connections, wedge grips or threaded-end testing fixtures. A self-aligning feature is desirable. Precautions

should be taken to prevent the specimen from slipping in the holding fixture.

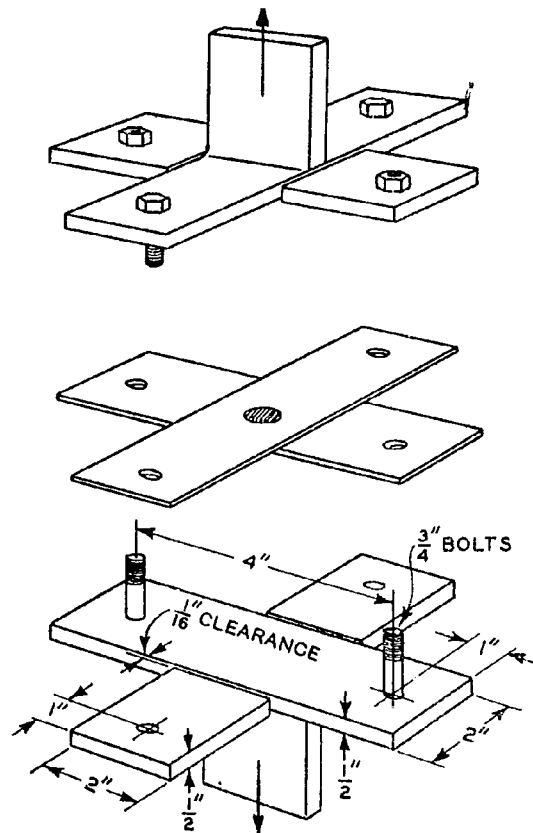


Fig. 5.3—Jig for Cross-Tension Test
(For thicknesses up to 0.191 in.)

The jig for holding the 3 x 8-in. cross specimen of Fig. 5.2 (b), is shown in Fig. 5.4. Figure 5.4 (a) shows one of the specimens in the lower portion of the testing jig.

Tension at right angles to the plate of this specimen is produced by applying compression to the jig holding the specimens. The U-shaped yokes with the holddown screws are used to partially restrain the specimen from bending by introducing semifixed ends to the beam represented by each separate plate. Fig. 5.4 (b) shows the specimen completely assembled in the jig with the compression head of the testing machine in contact with the jig and ready for applying load to the specimen.

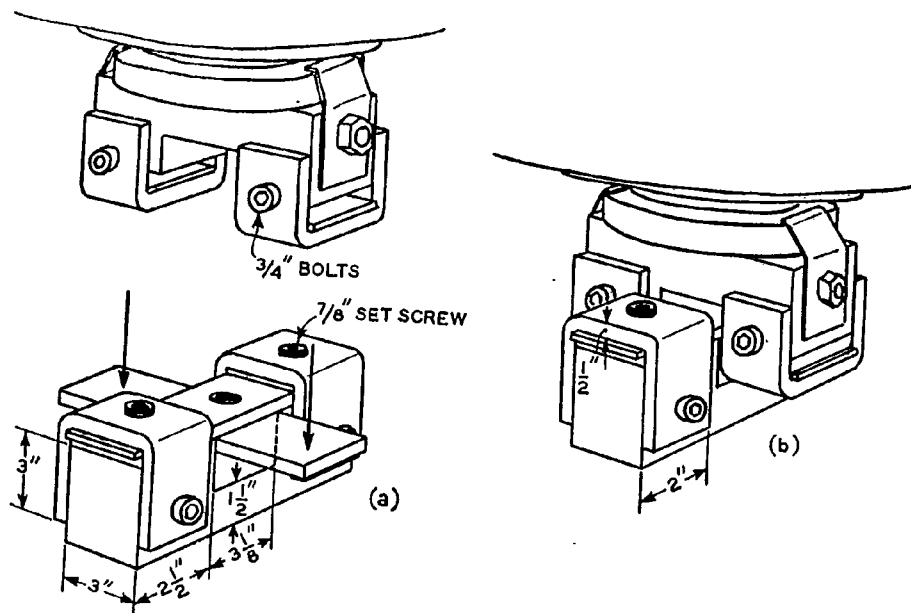


Fig. 5.4—Jig for Cross-Tension Test
(For thicknesses 0.191 in. and over)

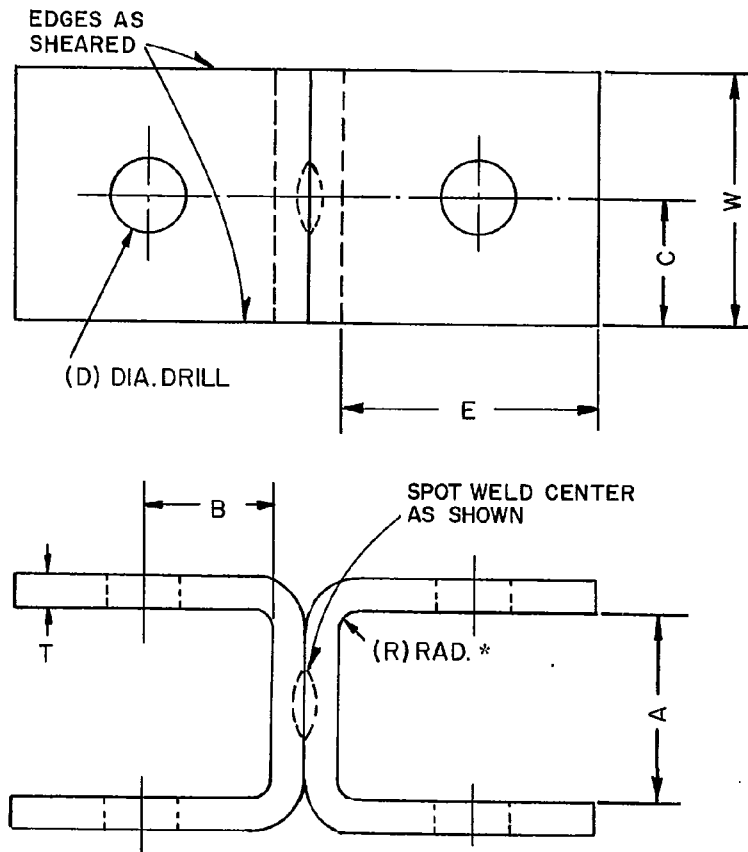
(b) *U-Tension Test* — A tension test may also be made on U-shaped specimens as shown in Fig. 5.5 (a). The U-sections are welded as shown and pulled to destruction in a standard testing machine. Supporting or spacer blocks must be provided, as shown in Fig. 5.5 (b), for confining the sample so that loading takes place at the weld.

The U-tension test is limited to those thicknesses and materials 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.

504.3 Impact Test (Test No. 3)

The impact test differentiates between different degrees of weld toughness. The four types described herein are: (a) *Shear-Impact Test*, (b) *Drop-Impact Test*, (c) *Shear-Impact Loading Test* and (d) *Tension-Impact Loading Test*. The shear-impact test is recommended as the most rapid, but is limited to thicknesses of 0.125 in. and under. For thicknesses over 0.125 in., the other tests must be used.

(a) *Shear-Impact Test* — A satisfactory shear-impact test for spot welds may be obtained by using the 2 x 6-in. tension-shear specimen, Fig. 5.1, and a modified 110 to 220 ft-lb pendulum-type impact testing machine. To satisfactorily test welds in sheets up to and including 0.125 in. in thickness, it is necessary to have bobs of different weights. Two interchangeable bobs made from magnesium alloy and steel are commercially



U-Test Specimen Dimensions (inches)

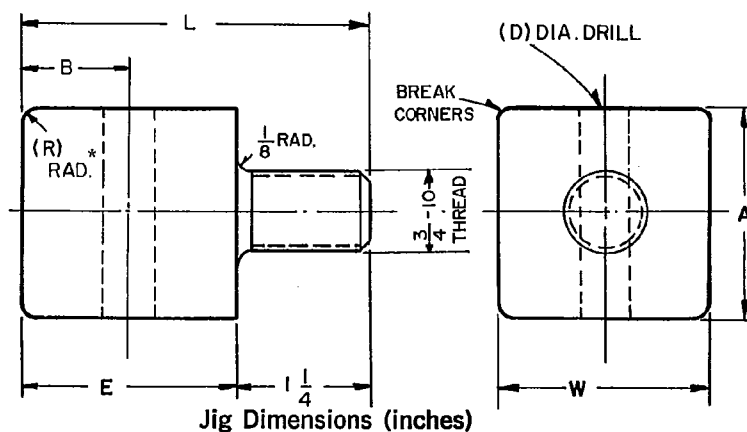
T (thickness)	W	A	B	C	D	E	R*
Up to 0.100	1	1	1/2	1/2	21/64	1	5/32
0.101 and over	2	2	1	1	9/16	2	1/4

* 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 desired to form these specimens without the necessity of heating as this will modify the results.

Fig. 5.5 (a)—U-Test Specimen

available. These provide 30 to 60 and 110 to 220 ft-lb testing capacities, respectively. Two-inch sheet metal testing attachments are commercially available.

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



T (thickness of specimen)	W	A	B	C	D	E	R*	L
Up to 0.100	1	1	1/2	1/2	11/32	1	5/32	E+1 1/4
0.101 and over	2	2	1	1	17/32	2	1/4	E+1 1/4

* 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 desired to form these specimens without the necessity of heating as this will modify the results.

Fig. 5.5 (b)—U-Tension Test Jig (two required)

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 setup is similar to that shown in Fig. 5.10. The residual swing of the pendulum indicates the impact load, in foot-pounds, necessary to break the weld. Care must be taken to properly tighten the wedge grips so that no errors are introduced by slippage of the specimen during test. If grip slippage is a serious problem, pin connections may be used to supplement the grips.

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 5 in. $\pm 0, + \frac{1}{16}$ 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 bob assembly is limited.

(b) *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 thickness much greater than 0.125 in., a different procedure must be used to apply shock loads to welds in the heavier gage materials. The most critical direction in which a shock 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 Fig. 5.6.

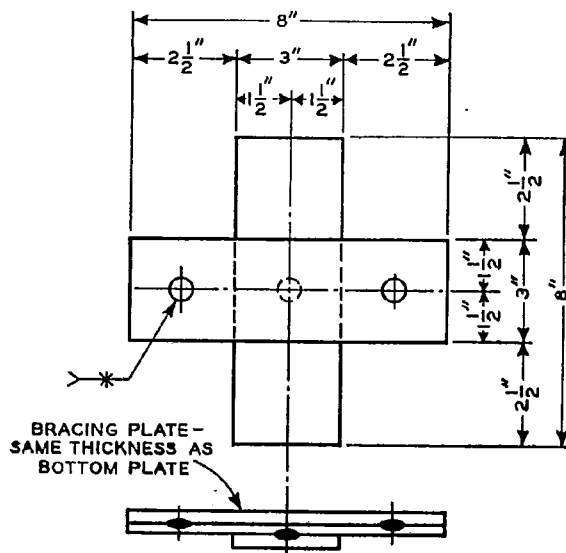


Fig. 5.6—Drop-Impact Test Specimen

In order to apply an impact load to a specimen of this type, a modified Freemont-type impact testing machine, which is commercially available, may be used. Weights of 50 or 100 lb. may be dropped from a height of 11 ft. to obtain maximum available energy values of 550 or 1100 ft.-lb. This range covers the usual impact strength values of heat-treated spot welds made in plain carbon and alloy steel combinations in plate thicknesses up to $\frac{1}{2}$ in. In order to obtain adequate velocity of impact it is recommended that the weights be dropped from heights 3 ft. and greater (approximately 14 ft./sec.). In order to reduce the bending of the specimen as much as possible, it is clamped by means of hold-down straps.

The residual energy after fracture is measured by means of a pair of calibrated springs. 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 a dial gage to be used to measure the maximum deflection of the springs (Fig. 5.7). 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 falling weight is guided by means of lubricated ways. The lower portion of the weight is forked to permit the weight to be applied to both sides of the lower plate of the specimen. The width of the opening between the two prongs of the

fork is made $3\frac{1}{8}$ in. to permit a small clearance between the inside surfaces of the fork and the clamped upper plate.

The results obtained with the 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 due to the fact that it is not possible 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, the resultant impact energy absorbed by bending will not be a good measure of the strength of the weld. On the other hand, severe plastic deformation of the plate material in the vicinity of the weld is a much better index 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 thus a true measure of weld toughness is not obtained.

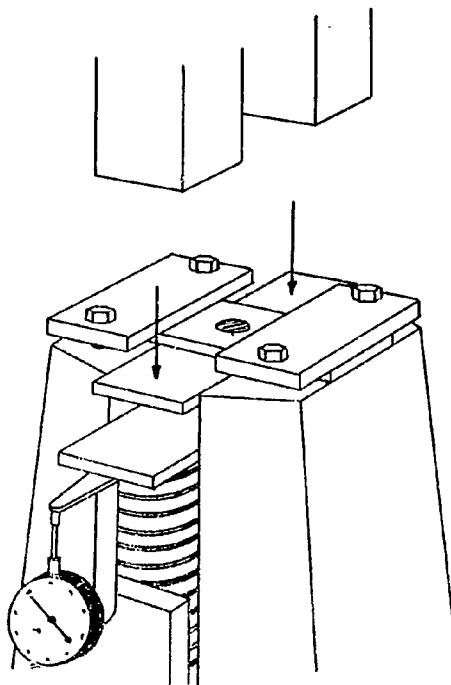


Fig. 5.7—Drop-Impact Test Machine

In order to avoid the possibilities for error 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 Fig. 5.6.

In this case the extra plate is placed in compression during the test, an action which prevents 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 and the precautions mentioned above with reference to the upper plate will insure 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) *Shear-Impact Loading Test* — This test utilizes the specimen made by joining two U-shaped sections back to back by a single spot weld as shown in Fig. 5.5 (a). The specimen is dynamically loaded in a pendulum type impact testing machine of 220 ft-lb. capacity. The test fixture is so designed that the forces applied in fracturing the specimen are essentially in shear as shown in Fig. 5.8. The velocity of the pendulum at the time of impact is approximately 18 feet per second. In other respects, the operation of this test is similar to that described for the shear-impact test. The energy (ft-lb.) consumed in fracturing the specimen and the

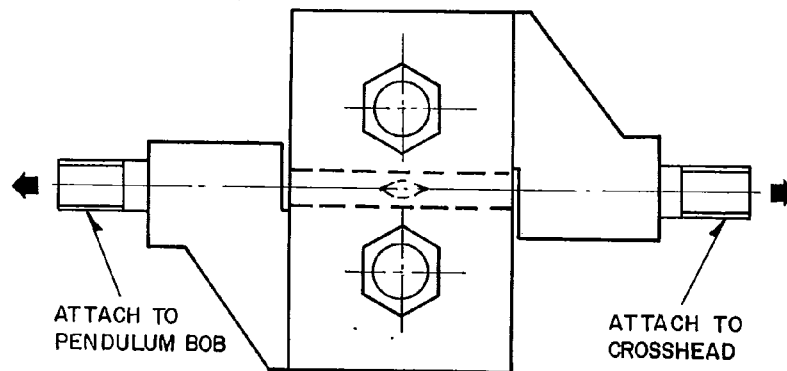


Fig. 5.8—Test Fixture for Shear-Impact Loading Test

manner of failure are recorded. The two photographs in Fig. 5.10 show the test fixture mounted in the pendulum bob, (a) during the fall, and (b) at the moment the cross head strikes the anvil.

(d) *Tension-Impact Loading Test* — This test also utilizes the U-Section test specimen shown in Fig. 5.5 (a). In this case the test fixture is so designed that the forces applied in fracturing the specimen are in tension as shown in Fig. 5.9. In all other respects this test is the same as the shear-impact loading test.

504.4 Fatigue Test (Tension-Shear) (Test No. 4)

The tension-shear fatigue test makes use of the tension-shear specimen (Fig. 5.1). Mounting holes must be drilled using utmost care to align the holes with the weld. The specimen is loaded in tension with a static load.

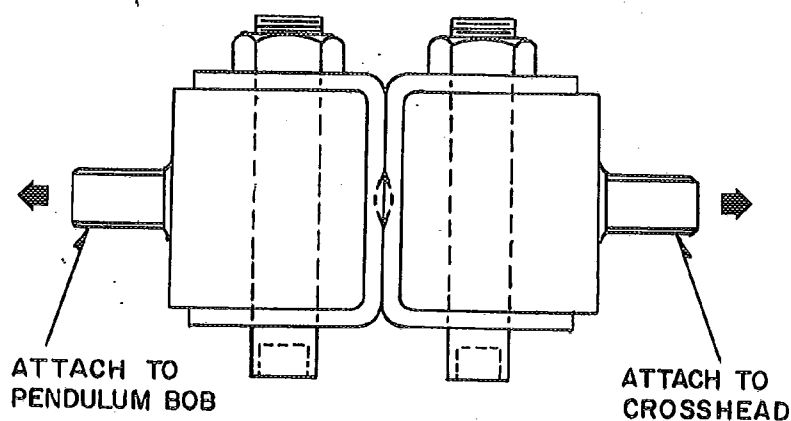


Fig. 5.9—Test Fixture for Tension-Impact Loading Test

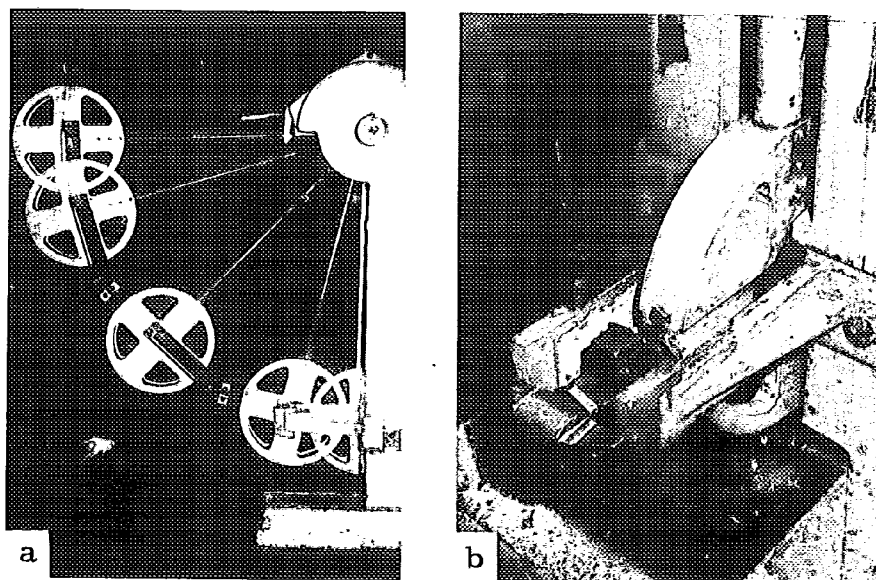


Fig. 5.10—Two Views of Impact Testing Machine with Shear-Impact Testing Fixture Mounted on Pendulum Bob.

- (a) Pendulum and fixture during fall.
- (b) Close-up as cross head strikes anvil.

A dynamic load is then applied and the dynamic load oscillated until failure of the specimen takes place (Fig. 5.11).

504.5 Macroetch Test (Test No. 5)

The purpose of this test is to determine the weld diameter and penetration as a shop control measure.

For testing seam welds, a longitudinal section may be used to determine

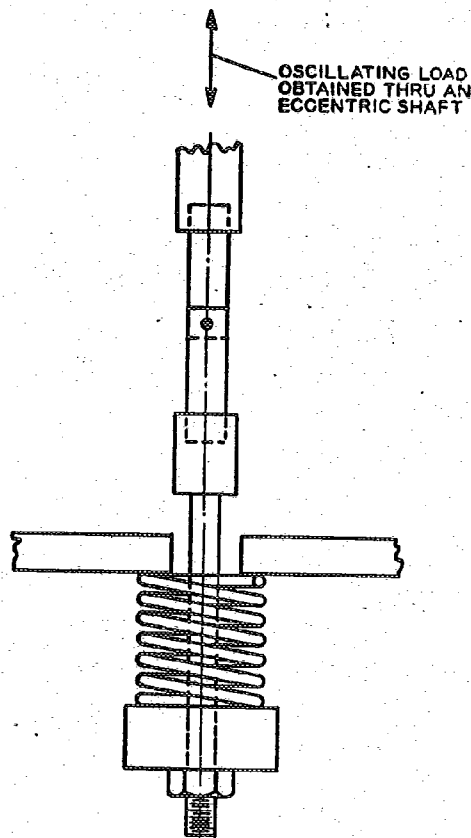


Fig. 5.11—Fatigue Testing Machine

the overlap of adjacent spots.

To prepare the specimen lay a straight edge across the weld and scribe a line on a diameter of the weld as judged by eye. Saw to one side of the line, filing or grinding the specimen to the line. Etch* until satisfactory definition is obtained between the weld zone and the unaffected base metal. The weld diameter may be measured by means of a pair of dividers and a steel scale. The penetration may be estimated. For more precise measurements these values may be determined with a microscope.

The same specimen may also be used for the Hardness Test (Par. 504.9) and the Bend Test (Par. 504.11).

For testing flash welds, section the material to obtain a plane perpendicular to the weld at about the mid-section with base metal on either side. Finish the sample by grinding to obtain a smooth surface and etch.

This test is intended as a quick check and its accuracy depends upon the care taken in preparation of the sample. Where more accurate information is required the samples require mounting and careful preparation to obtain

* For suitable etching solutions see ASTM Specifications E-3, Methods of Preparation of Metallographic Specimens, latest revision, or ASM Metals Handbook.

the true diameter.

504.6 Pillow Test (Test No. 6)

Seam welding is an extension of the spot-welding principle to a condition where the spots overlap providing a continuous weld. This type of weld is usually employed where tightness is required. A test approaching operating conditions furnishes the best measure of weld quality. For this purpose, two flat plates of the same thickness as used in production are prepared and welded around the outside edge sealing the space between the plates. A pipe connection is then welded to the hole as shown in Fig. 5.12 and the assembly attached to a hydraulic system. Pressure is then applied.

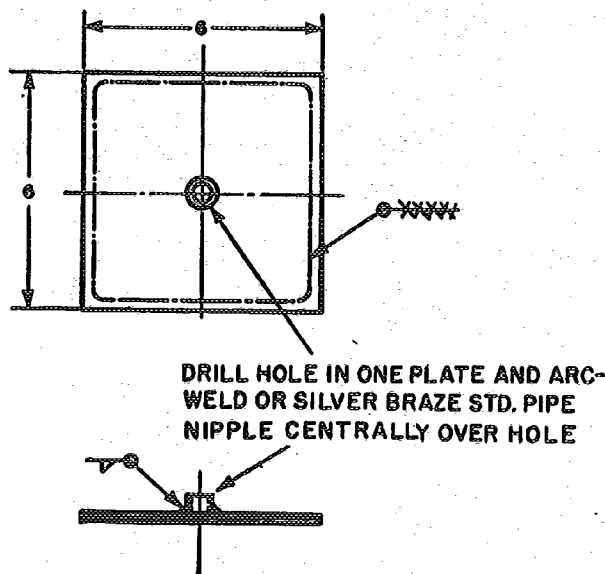


Fig. 5.12—Pillow Test for Seam Welds

It may be necessary to restrict deformation of the pillow by inserting a plate above and below it while testing, particularly in soft material, as the pillow so distorts as to cause excessive loading in some spots with hardly any loading in other spots.

The measure of a good weld is no leakage at a prescribed pressure or when failure occurs in the base metal.

504.7 Radiographic Test (Test No. 7)

X-ray inspection of highly stressed and critical spot welded assemblies is often required, especially of aircraft structures and jet engine parts.

X-ray inspection will disclose flaws such as cracks, shrinkage cavities, spits, and mislocation on blind pieces. It will not directly determine if fusion is present, nor will it reveal the weld diameter except in a few

light alloy materials where copper and zinc segregation may occur around the weld periphery and so leave an image on the radiograph. In most other materials, all that can be seen is surface indentation and forged area around the weld nugget in addition to defects that may be present.

The defects that occur in resistance welds are extremely small, and, in order to detect them, an effort must be made to assure high contrast and definition (detail). Practices satisfactory for the examination of arc welds are generally not sensitive enough for examining spot welds.

The requirements of high contrast and definition are met by using fine-grain high-contrast film, low x-ray tube voltage, very small focal spot x-ray tubes, large d/t ratio (where d = distance from tube target to the object being examined and t = thickness of the object, assuming film to be in close contact with the object), and high-contrast developing technique. Intensifying screens are never used since the defects are often smaller than the grain size of the fluorescent material used in the screen. Instead, direct exposure on non-screen type film is used for light alloys and thin sections of ferrous and heavier materials. Metallic filter screens (usually 0.005 in. lead) are used in front and back of the film for average and heavy sections of ferrous and heavier materials. It is good practice wherever possible to back up the film holder with 0.060 in. lead or lead-rubber to prevent stray radiation from fogging the film from the rear. Examination of the film images should be made with the aid of a magnifier with a power of about 5X.

Standard equipment that meets the above requirements is available from most x-ray machine manufacturers. The most useful range of voltages lies between 20 kilovolts and 140 kilovolts, aluminum requiring from 20 kv to 100 kv, depending on thickness, and ferrous alloys and nickel-base alloys requiring between 60 kv and 140 kv, again depending on thickness. The 20 kv to 50 kv equipment must include a beryllium tube since a glass window absorbs the low voltage radiation. Whenever possible, a small focal-spot tube should be used to assure best detail rendition. A popular size focal spot is 3 mm. The beryllium window may be designed with a 1.5 mm focal spot, allowing greater detail. For safety reasons, shock-proof equipment should be used.

Radioisotopes are not useful for examination of spot welds because of the inherent low contrast of films when used with gages of material thinner than half an inch. The only isotope that approximates x-ray quality is thulium 170 with a gamma radiation equivalent to 85 kv x-rays. It, however, has a half-life of only 127 days and would have to be re-activated frequently.

504.3 Torsional Test (Test No. 8)

Two types of torsional test are used as described below.

(a) *Twist Test* — A standard tension-shear specimen (Fig. 5.1) may be used as a twist test specimen to determine the weld diameter, as well as the angle of twist at failure. One end of the specimen usually is

clamped edgewise in a vise, in a horizontal position. A sleeve, having a protractor mounted at its end, is slipped over the protruding end of the specimen so that the protractor is centered on the weld. The sleeve is rotated horizontally (i.e., in a flat arc about the vertical centerline of the weld) until failure occurs. The angle of twist at failure is measured and recorded.

(b) *Torsional-Shear Test*—The torsional-shear test for evaluating spot welds may be used where a measure of strength and ductility is required. A typical set up for this test is shown in Fig. 5.13. Torsional shear is applied on the weld of a square test specimen by placing the specimen between two recessed plates, the upper of which is held rigid by means of a hinge while the lower is fastened to a rotatable 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

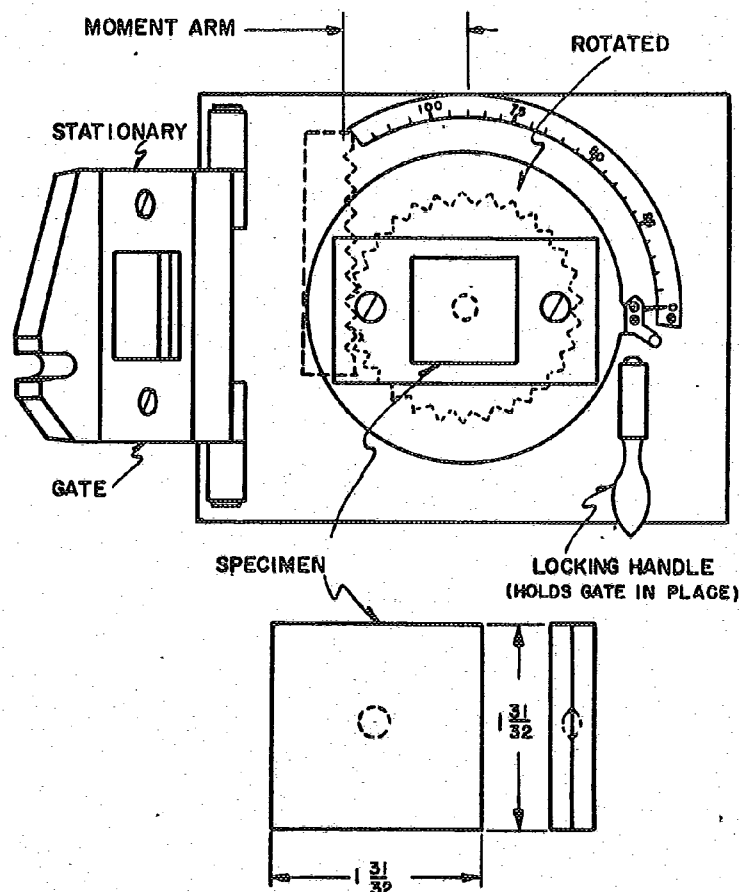


Fig. 5.13—Test Specimen and Typical Equipment for Torsional-Shear Test.

and that the weld be centrally located with respect to the axis of rotation.

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 pounds by the moment arm in inches).
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.)

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 values obtained by tests (ultimate torque, angle of twist, and weld diameter) to indicate quality. However, it is advantageous to combine these factors, establish a weld quality index number, and then use a control chart for quality control purposes.

This may be done by using the standard torsional formula:

$$S = \frac{Mc}{I}, \text{ where}$$

S = torsional-shear stress (lb. per sq. in.),

M = torque (lb-in.)

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

I = moment of inertia (in.⁴).

The stress values obtained for the external fibers, termed the Modulus of Rupture, is directly proportional to the straight-shear stress, and was found by actual test on low-carbon steels to be approximately twice the straight-shear stress.

In order to evaluate the straight-shear strength, using torsional testing, it is therefore necessary to use the following equations:

$$\text{Torsional-shear stress} = 2 \text{ (straight-shear stress)} \quad (1)$$

$$\frac{Mc}{I} = \frac{2 \text{ (straight-shear load)}}{\text{area}} \quad (2)$$

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

$$\frac{T \left(\frac{D}{2} \right)}{\frac{\pi D^4}{32}} = \frac{2L}{\frac{\pi D^2}{4}}$$

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

Solving above equation for L (straight-shear load),

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

$$\text{Straight-shear load (lb)} = \frac{2 (\text{ultimate torque, lb-in.})}{\text{diameter (in.)}} \quad (3)$$

The above formula gives approximate relation between straight-shear strength and torque required to shear the weld, thereby permitting evaluation of the straight-shear strength by torsional testing.

The operator of the torsional testing machine multiplies torque by 2 and divides by weld diameter to obtain weld straight-shear strength.

When tested and computed as indicated above, minimum strength values for single spot welds may be established and arranged in tabular form for reference. The table below may be considered typical.

*Typical Minimum Strength of Single Spot Welds
in Low Carbon Steel*

<i>Minimum single thickness (in.)</i>	<i>Approx. weld diameter (in.)</i>	<i>Minimum straight- shear strength* per weld (lb)</i>
1/8	1/2	6,000
3/16	5/8	10,000
1/4	3/4	15,000

* As obtained in equation (3), based on ultimate torque.

By using the product of straight-shear strength and angle of twist as an index of weld quality, both shear strength and ductility influence the results.

Weld quality index numbers can be plotted on a quality control chart.

504.9 Hardness Test (Test No. 9)

A macroetch specimen (see Test No. 5, Par. 504.5) is prepared, exercising care to avoid overheating of the weld area in cutting so as not to affect the surface hardness. A second cut parallel to the first should be made to obtain a sample of suitable height to mount in the hardness tester. The weld section is finished with 3/0 paper and etched. Care should be taken to select a hardness test method so that the impression does not distort the edge of the specimen. (For further details refer to data on methods of hardness measurements in *ASTM Standards, General Testing Methods*).

504.10 Peel Test (Test No. 10)

The peel test is a simple shop test that can be made with a minimum of equipment but if correlated with tension-shear and tension tests makes an ideal control test. It is applicable to all thicknesses of material up to

and including $\frac{1}{8}$ inch.

The test consists of peeling apart, to destruction, a test specimen ob-

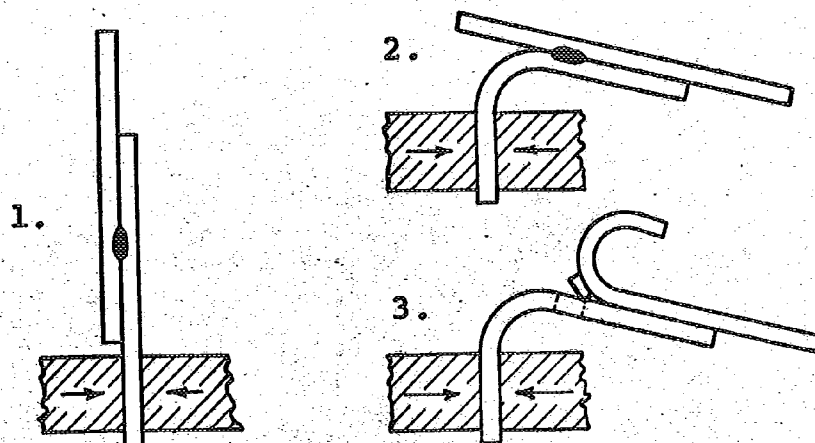


Fig. 5.14—Peel Test

Step 1, Grip in vise or other suitable device. Step 2, Bend specimen. Step 3, Peel pieces apart with pincers or other suitable tool.

tained by lapping two strips of metal and joining them by a single weld as shown in Figs. 5.14 and 5.15 (top). If it is desired to determine shunting effect several spots can be made using the desired spacing and then the sample cut transversely before peeling is started, using the last weld made as the test sample. Three welds are recommended for this adaptation as shown in Fig. 5.15 (bottom).

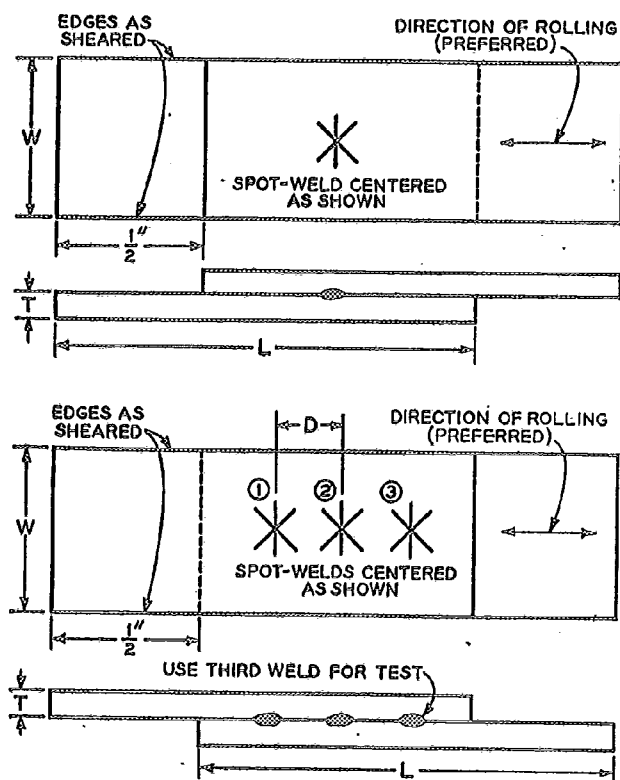
The size of the fused zone can be measured to the nearest $\frac{1}{32}$ in. by means of this test. An indication of the penetration is also obtained in that if sufficient penetration is not present, the metal from one piece will not be torn out in its entirety. Irregularity of shape of torn metal also indicates insufficient penetration.

This test will apply to spot welds or single projection welded studs or parts.

504.11 Bend Test (Test No. 11) — (Aluminum & Aluminum Alloys)

The bend test is a relatively simple shop test included to provide a quick check test of production spot-weld soundness, particularly freedom from cracks (microfissures). It is intended as an aid to process control rather than a requirement. It can be performed with equipment which is readily available in most shops and requires only visual examination for evaluation. The test is specifically limited to a maximum of two thicknesses of 0.125 in. and has been developed for use on aluminum.

The bend test is not precise enough for equipment calibration nor for evaluating machine performances nor the setting up or qualification of welding schedules.

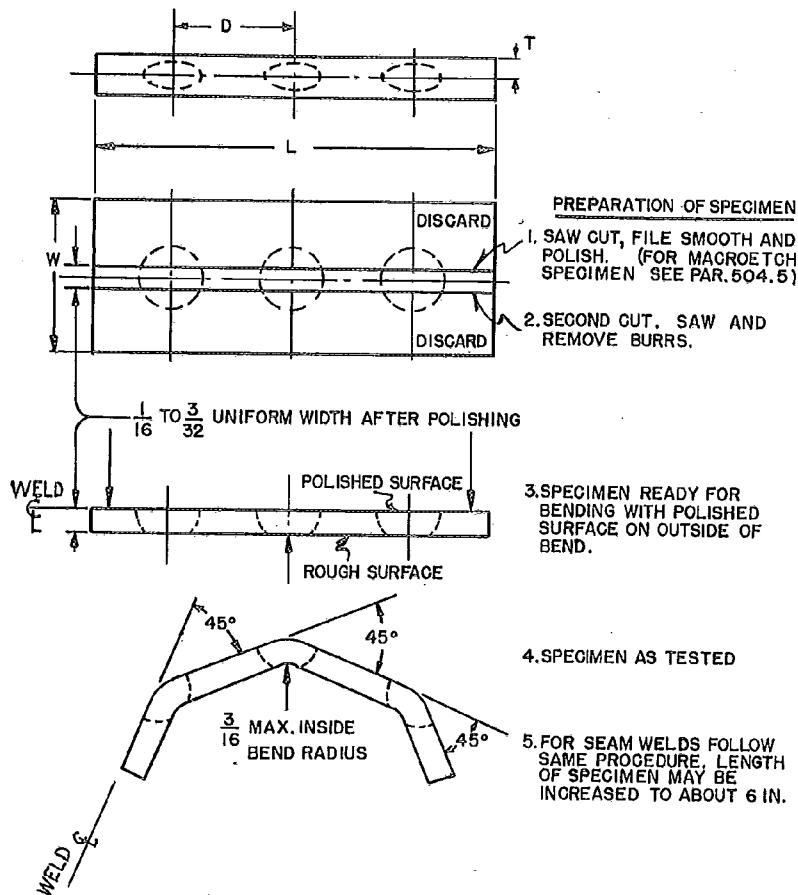


T (thickness)	W	L	D
up to 0.029	$\frac{5}{8}$	2	See minimum
0.030 to 0.058	1	3	weld spacing in
0.059 to 0.125	$1\frac{1}{2}$	4	Recommended Practice

Fig. 5.15—Peel Test Specimens

The test consists of bending a test specimen which is removed from a routine macrosection containing three welds as shown in Fig. 5.16. The bend test specimen is bent along its length to the angles shown in such a manner as 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 the burr.

After bending the specimen is examined for the presence of cracks or any other surface defects. The same test can be used for seam welds in which case the specimen length may be increased to allow about $1\frac{1}{2}$ in. spacing between bends.



T (thickness)	W	L	D
up to 0.029	$\frac{5}{8}$	2	See minimum
0.030 to 0.058	1	3	weld spacing in
0.059 to 0.125	$1\frac{1}{2}$	4	Recommended Practice

Fig. 5.16—Bend Test Specimens

504.12 Eddy Current (Electromagnetic Testing) Test No. 12

Electromagnetic tests are defined for the purposes of this article as tests which require the object under test to be subjected to the influence of an alternating electromagnetic field. The electromagnetic tests are used to detect and, in many cases, to evaluate surface or subsurface discontinuities which may occur in the form of cracks, seams, voids, etc. The effect of the electromagnetic field on the article may be twofold: eddy currents are induced and, if the material is magnetic, magnetic fields are set up. A complete separation of these two effects in magnetic materials is not readily

accomplished; however, by selection of the magnetizing frequency and by proper design of the test circuitry, a high degree of discrimination may be obtained.

When testing nonmagnetic materials the test depends entirely upon eddy currents. When testing magnetic materials, both eddy current and magnetic effects are obtained. With magnetic materials the classification of testing as eddy current testing or magnetic testing actually depends upon relative emphasis rather than upon complete separation. For this reason, it is common practice to describe a test as either magnetic or eddy current depending upon the characteristics upon which conclusions are based.

PRINCIPLE OF OPERATION

The alternating electromagnetic field is usually produced by an inductor positioned in close proximity to the article under test. The inductor may assume a variety of shapes and arrangements. The selection of shape, dimension and arrangement is governed by the sensitivity required to detect the discontinuities involved, by the orientation of the defects sought and by the geometry of the article.

In eddy current tests the magnitude and direction of the eddy currents are altered by discontinuities in the metal. The change in the eddy currents is detected by a detector coil which acts upon appropriate electronic circuitry to register the discontinuity. Since eddy currents may be induced in any conductor, eddy current testing may be employed on either magnetic or nonmagnetic materials.

In magnetic testing, the distribution of magnetic current or flux is affected by magnetic variables associated with discontinuities in the material. The critical variable can be made to produce a significant change in the flux distribution. The effect of that change in the testing circuitry reveals the existence of the discontinuity. Magnetic testing is obviously limited to use on magnetic materials.

Changes in the eddy current or the magnetic flux may be interpreted by means of several different electrical variables such as voltage, current, impedance, phase, or some combination thereof. These variables are analyzed electronically to provide the desired information in a useful form. Electromagnetic tests may be absolute measurements relating to the discontinuity itself or comparisons of variables relating to both the discontinuity and the adjacent sound material.

PRECAUTIONS

If the material is tested by travel through or past a testing station, the minimum discontinuity that can be detected is limited by the frequency of the alternating magnetic field used and by the travel speed of the material. Sensitivity to a defect of given dimensions decreases rapidly as the spacing between the material and the inductor is increased.

Since sensitivity to subsurface defects is dependent upon the effects of the eddy currents and the flux distribution, it is therefore also de-

pendent upon the frequency used and permeability and conductivity of the material.

In preparing the material to be inspected any surface dirt which may be magnetic or electrically conductive must be thoroughly cleaned off the material. Before testing is begun, the instrument must be calibrated. The common practice in calibration is to adjust the response of the instrument to discontinuities of known dimensions.

APPLICATION

Electromagnetic tests may be applied to welds of various configurations. The design of the inductor which is used for producing the magnetic field is usually dependent upon the geometry of the material to be tested and on the type of defects that are sought. The technique most commonly used on welded tubular products involves a coil or coils which surround the material.

These coils can be designed so as to induce a circumferential current flowing through the entire tube wall. Such an arrangement enables the user to detect defects anywhere throughout the wall of the tube. However, for the purpose of inspecting only the weld in a longitudinally seam welded tube, detector coils tangent to the tube near the weld provide more accurate information regarding the presence and the magnitude of small defects. The information gathered by the tangent probe coil is transmitted to the test circuit and analyzed electronically.

Other eddy current test techniques employ probe coils that do not surround the material to be tested. One that has been used with considerable success provides a probe coil with its axis at right angles to the axis of the material. It induces eddy currents following the shape of the coil in the portion of the material closest to the coil. The circuitry used in this technique is responsive to changes in the current flow caused by discontinuities as the article progresses past the probe coil.

The instrumentation that may be used with electromagnetic testing has almost limitless combinations. A number of electromagnetic testing instruments are available commercially; others have been specially constructed for specific applications. The possibilities of still more useful combinations are numerous.

The choice of frequency to be used to excite the electromagnetic field depends upon the depth of penetration of the inspection beneath the surface of the part. Frequencies may vary considerably, but are usually in the range of 500 to 20,000 cycles per second. The higher frequencies are usually used for small diameter, light-wall nonmagnetic tubing.

When using eddy current tests on magnetic materials, it is often desirable to magnetically saturate the object while it is being tested. This has the effect of suppressing the influence of certain disturbing magnetic variables. Saturation also increases the penetration of the eddy currents. A common method used to obtain saturation is to surround the article with a dc solenoid. A water-cooled, low-voltage, high-current coil arrange-

ment has been found satisfactory for production use.

In developing an electromagnetic test, it is usually necessary to establish the relationships between all kinds of natural defects, harmless variables and the artificial defects used for calibration purposes. It has been generally found out that sensitivity to a defect is not difficult to obtain and is not a major consideration. Contrary to a common assumption, the practical utility of a nondestructive test in volume production cannot be measured by sensitivity alone. It depends even more on its ability to discriminate between actual defects and other variables in the article being tested. The problem of discrimination is often complicated by the fact that a variable which is considered an objectionable defect in one application may be perfectly acceptable in another application. It follows then that in selecting an electromagnetic test, a vital consideration is the ability to discriminate between the many variables existing in the article to be tested.

ADVANTAGES

The two most significant advantages over other inspection methods offered by electromagnetic tests are:

1. They can, in many cases, be completely automated so as to provide automatic inspection at high speed and at relatively low cost.
2. Under certain circumstances the indications which they produce are proportional to the actual size of the defect, making the tests useful for grading and classifying.

Caution: Depending upon the length of time after testing and what handling the material has received it is possible some residual magnetism may remain. If this affects the welding procedure steps to demagnetize the parts will be required.

504.13 Surface Resistance Analyzer (Test No. 13)

The equipment is used to measure the surface resistance between the faying surfaces of two overlapped unjoined plates to be resistance welded.

The measurements are useful to check or monitor a cleaning method or material surfaces as received.

The equipment consists of a force system, with electrode tips, a dc power supply and a means for measuring the voltage drop.

It is recommended that 500 to 1000 pounds force be applied on the electrode tips (minimum $\frac{1}{2}$ in. diameter — machined with a 2 to 3-in. radius dome).

The power supply should have capacity to supply 12 to 50 amp direct current.

Commercial equipment is available. This equipment is *not* a method of checking welds but of checking the surface resistance of metals prior to being welded.

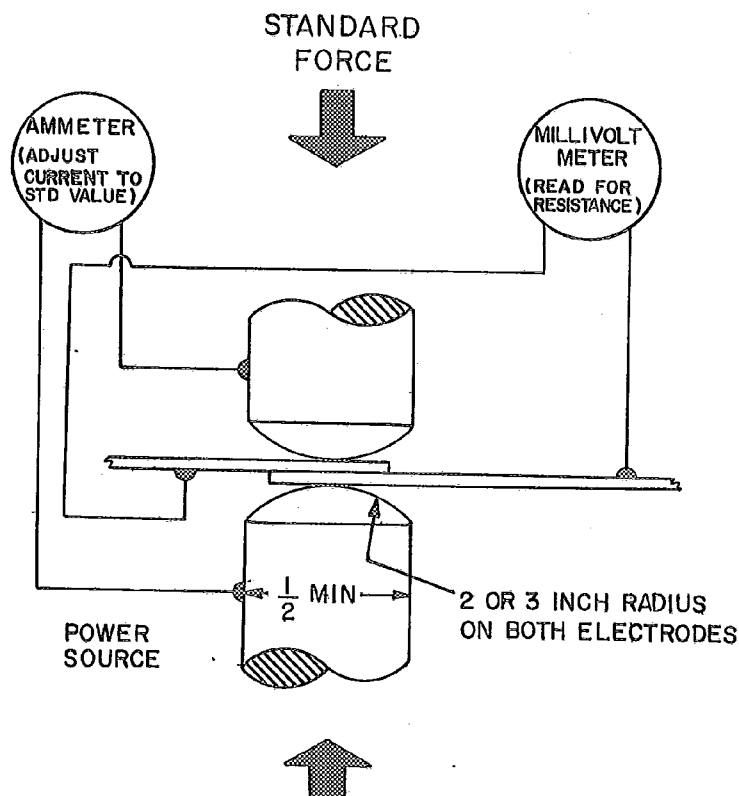


Fig. 5.17—Diagram of Surface Resistance Analyzer.

505. EVALUATION OF WELD CONSISTENCY

When a series of test results are to be evaluated in terms of consistency, it is recommended that the ASTM methods be adopted. These methods are described in detail in the *ASTM Manual on Quality Control, STP-15C*, and are based on statistical theory. An extensive discussion on the statistical control of weld quality will be found in the *Welding Handbook, Section 3, Fifth Edition*. The use of the statistical method provides the following advantages:

1. A quantitative measure of the degree of consistency of a complete welding process can be obtained.
2. A comparison can be made of consistencies resulting from different techniques, machines, materials and maintenance procedures.
3. It permits the determination of proper values of average strength to be used in the shop if specified minimum strengths are to be maintained

without exception.

4. It permits the establishment of proper control limits within which production samples must fall if the results are subject only to normal variations. When a production sample falls outside of the control limits, an abnormal change in one of the elements of quality control has occurred and should be corrected.

5. It permits the quantitative evaluation of the effectiveness of improvements in quality control.

6. It permits the comparison of quality in different shops working on similar types of production.

7. It makes possible the comparison of test results from different laboratories or shops. It is thus a measure of the validity of conclusions arrived at from experimental investigations.

8. It furnishes design engineers with a quantitative measure of weld consistency obtainable in the shop.

When the statistical method is applied to a series of test results, the most useful measure of consistency is the *coefficient of variation*, defined below:

The *coefficient of variation* is the standard deviation of a number of observed values, expressed as a percentage of the average value.

The *standard deviation* is the root-mean-square deviation of the observed values from their average.

Obtaining the average value of a series of observations is a simple case of addition and division. The standard deviation is a little more difficult to calculate. The first step consists of obtaining the sum of the squares of the observed values. This sum is divided by the number of observed values. From the quotient the square of the average observed value is subtracted. The standard deviation is obtained by taking the square root of the remainder. Simplified methods for computing the standard deviation are fully described in the ASTM Manual.

Presentation of Data.—Whenever the results of a series of tests are recorded or presented for publication, the following information should be provided:

1. Number of observed values.
2. The average of the observed values.
3. The standard deviation of the observed values, or the coefficient of variation.
4. The range, which is the difference between the largest observed value and the smallest observed value.
5. The type of test and the units in which the results are expressed.

Sampling.—One of the most important factors involved in the evaluation of consistency is the obtaining of reliable samples. Great care must be

exercised to insure that these are truly representative of production. This factor can be controlled by careful selection and training of the individual who is to collect the samples.

506. CONTROL OF WELD QUALITY BY STATISTICAL METHODS

When weld quality is to be controlled by statistical methods, the control chart methods of the American Standards Association may be used. These methods are fully described in Standards Z1.1-1958, *Guide for Quality Control*; Z1.2-1958, *Control Chart Method of Analyzing Data* and Z1.3-1958, *Control Chart Method of Controlling Quality During Production*, published by the American Standards Association.

These standards employ practically the same methods and terminology that are used in evaluating weld consistency. They provide means for establishing minimum and maximum limits for judging the quality of production on the basis of periodic samples of a limited number of specimens. Variations of test results within the control limits may be ascribed to probable errors. Test results falling outside of the control limits are an indication of an abnormal variation in one of the elements controlling the results. The cause of the abnormal variations should immediately be investigated and corrected.

Before the degree of consistency that is to be maintained can be determined, it is necessary to collect and analyze data which are representative of past and current production. A decision must also be reached regarding the frequency of sampling and the number of specimens in a sample. Having determined the proper average value and the standard deviation based on past and current production, and having also determined the number of specimens per sample, the control limits may be calculated by means of factors which are tabulated in the ASA publications referred to above.

Control Charts.—The control limits established above, may be indicated graphically on charts upon which the average results of the periodic sampling are plotted. This control chart method gives a continuous visual indication of the test results. Whenever the test results fall outside of the control limits, an investigation should be made to ascertain the cause, and the difficulty corrected. The range of variation of individual specimens in a sample may also be plotted on the same chart.

507. RESISTANCE WELDING STATISTICAL QUALITY CONTROL

507.1 General

The application of statistical control to production quality has three prime objectives: (1) to reduce the number of rejections and machine shutdowns due to poor performance; (2) to assist in establishing the optimum specification limits of satisfactory quality; and (3) to provide a reasonably reliable measure of actual production quality. When these objectives are finally achieved, the net production will have been improved because of greater quantity, lower costs and better quality.

The basic principles of statistical control have been thoroughly worked out and are widely used in industry. Briefly these principles are:

1. To select samples of actual production and test them for performance to specifications.
2. To estimate the probable quality, or conformance, of all production by analysis of samples.
3. To predict the future quality by considering the trend of past and present quality.

The methods of sampling, of extracting data from the samples and arriving at a decision as to whether to permit further use of the machine setup that produced the sample constitute the regulatory system.

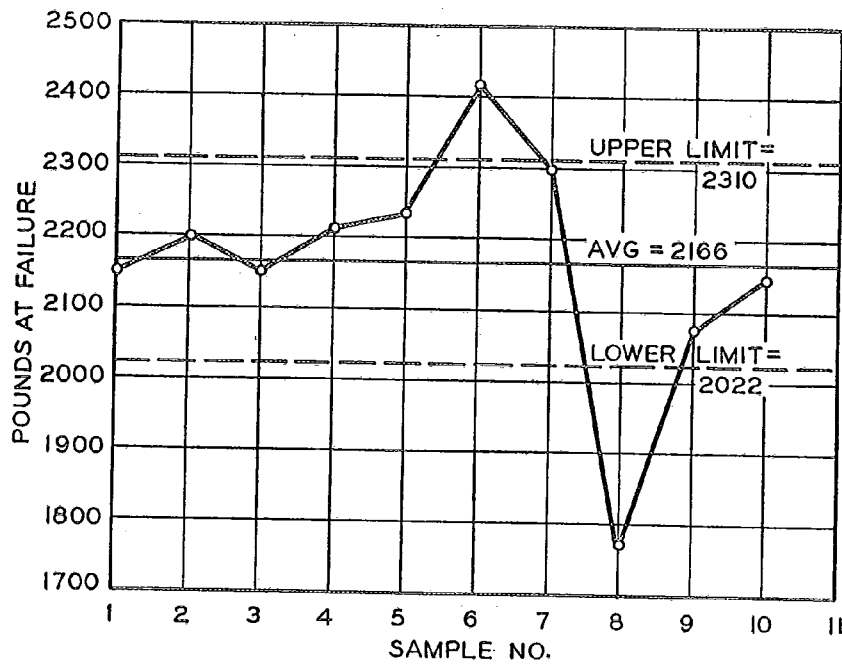
In connection with the selection of the statistical control system, it is probably obvious that the smaller number of variables that must be kept under control, and the fewer the charts and records that must be maintained, the faster and more economical will be the functioning of the system. This leads immediately to the conclusion that the various machines in the shop which are used to weld the same or similar materials should themselves be as nearly equal in adjustment and performance as possible.

Thus, although a complicated system could be adopted that would operate over a number of machines with different and varying characteristics, a much more economical system could be used if all the machines were first stabilized and then all the nearly similar machines were standardized before applying the statistical control.

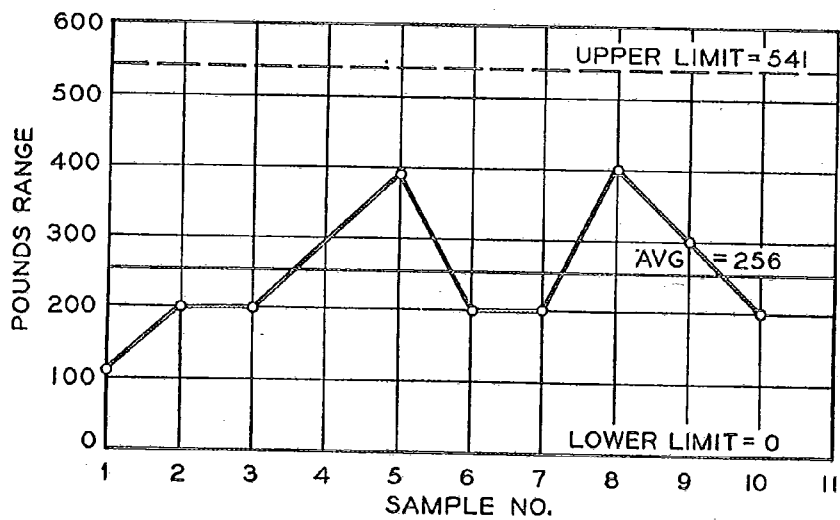
507.2 Procedure in Installing a Statistical Control System

Having first standardized the spot-welding machines, the installation of the statistical control system should be as follows:

1. Obvious faults in the process or equipment should be corrected.
2. The quality of the spot-welding production should be surveyed by obtaining a representative sample, of about 100 spot welds, of the output of each machine. This should first be done with a single thickness and material representing the average output of the shop. All machines should be included, and all conditions such as surface condition, machine setup and operating procedure should be in accordance with the tentative shop standards.
3. The data collected in the shop survey should then be analyzed. The average strength should be calculated and used as a measure of strength, and the *standard deviation or coefficient of variation* calculated as a measure of consistency. The range (difference between maximum and minimum strengths) is not an accurate measure of consistency, although for ten or fewer spot welds the standard deviation is probably no better; however, the initial sampling tests should contain at least 50, preferably



(a) CONTROL CHART FOR AVERAGES



(b) CONTROL CHART FOR RANGE

Fig. 5.18—Control Charts

100 or more, welds each.

4. Using the results of the general survey, the next step should be to establish maximum and minimum allowable values of average strength and range for future small samples (five to ten welds) from the same machines. Such allowable values should be derived from a careful analysis of the larger body of 50 or 100 samples taken during the survey, and should be so selected that there is a high degree of probability that if a small sample satisfies the imposed conditions, the entire body of welds will be of about the same strength and consistency, as was the case with the body originally surveyed. Tests whose results fall within the limits are then taken as indication that the machines have not changed and that they are therefore still doing acceptable welding.

5. Control charts similar to that shown in Fig. 5.18 should then be established, and would afford direct control of the use of the machines. Any machine whose average spot weld shear strength or range falls outside of the limits on the control chart could reasonably be assumed to be operating differently than when first tested. A discrepancy in average strength might perhaps call for the recalibration of some instrument or an adjustment of the line voltage or other variables. If the range becomes excessive, it could be assumed that something is not as it should be; perhaps the surface condition has changed, or electrical troubles are responsible. Practice will quickly develop the ability to interpret the control chart in terms of maintenance procedure.

6. Data obtained from hourly or other regular sampling should be plotted immediately and would make possible a long-time and accurate evaluation of output quality. The number of spots in these samples would, of course, be much smaller than in the initial 100-weld test, but they would be taken so frequently as to make possible the drawing of a continuous quality record. The trends of average strength and range from sample to sample on any machine would be employed as an indication of whether trouble is likely to occur, thus making it possible to correct faults before they get so bad as to interfere with production. This is one of the basic objectives of a control system.

7. As the results of the system improve the quality of production, the number of spots taken in each periodic test could be reduced, and the system cost gradually decreased to a minimum.

507.3 Procedure for Determining Control Factors

Reference will be made to Fig. 5.19, which is a graphical representation of a typical process which is normally distributed about its mean, $\bar{X}$. The definitions of the terms used in Fig. 5.19 follows:

Tail Area, P_t . This area to the left of the specification minimum (expressed in percent of the total area under the distribution) is called the "lot tolerance percentage nonconforming." The area represents the percent of spot welds whose shear strength can be tolerated to fall below

the specification minimum in the long run. Values of P_t equal to 1, 0.5 and 0.1% are suggested as reasonable. In other words, the consumer or designer will agree to accept the process and design if the quality for the greater percent of the time does not become worse than the agreed upon percent nonconforming.

Lot Tolerance Average $\bar{X}_p$. The lot tolerance average is the average value of the process which for a given standard deviation, σ , will give the tail area, P_t , as shown. If the standard deviation becomes smaller, the distribution will become narrower, permitting a lowering of $\bar{X}_p$ in order to maintain a constant area P_t and vice versa. If the standard deviation is fixed, the lot tolerance percentage nonconforming can be changed by shifting $\bar{X}_p$ to the right or left.

Distribution of Means. If instead of making a frequency distribution of single observations, rational subgroups of size n are selected and averaged, the distribution of these arithmetic means will have the same average as the average of individual observations, but the distribution will be somewhat narrower by the same amount that the standard deviation is reduced. If the standard deviation of the distribution of single observations equals σ the standard deviation of the distribution of means will equal $\sigma/\sqrt{n}$. The larger the sample size, the narrower the distribution of means.

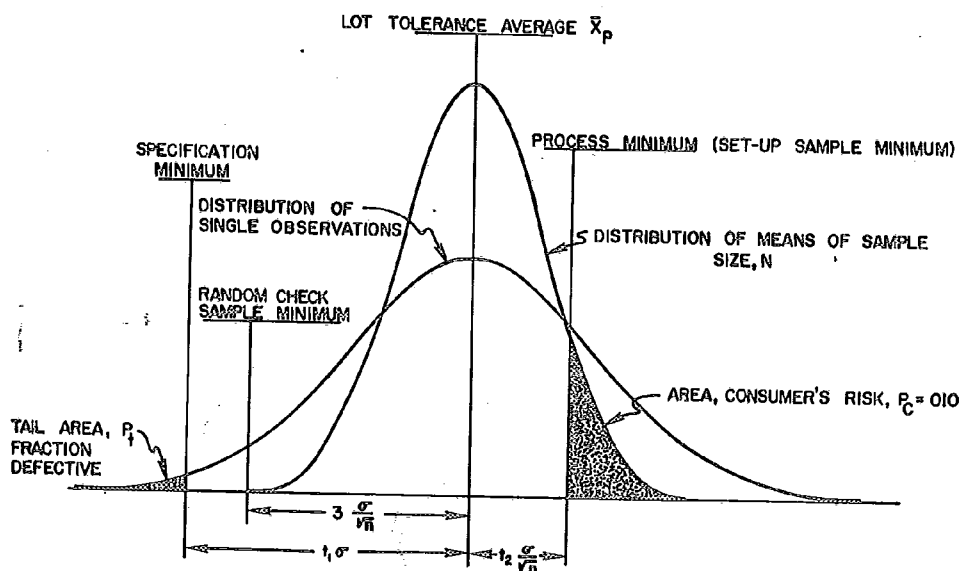


Fig. 5.19—Graphical Representation of a Typical Welding Process and Location of Process Minimum

Process Minimum. This is the minimum value which the average of a sample size n may fall in setting up a machine before spot welding starts.

The reason for its position with relation to the distribution is described under "Consumer's Risk."

Consumer's Risk, P_c . The quantitative value of the consumer's risk is represented by the area, P_c , to the right of the process minimum in the distribution of means. For the sake of uniformity and convenience, the consumer's risk is usually set at 10%. The consumer's risk is the probability of accepting welding of quality $\bar{X}_p$ with tail area P_t . In other words, suppose we had prior information that the quality of the product is represented by the distribution whose average is $\bar{X}_p$ and tail area P_t with the distribution of means as shown in Fig. 5.19. If we accept samples when they are equal to or above the process minimum and reject them the rest of the time, we will be accepting samples not more than 10% of the time in the long run even though the samples come from a distribution of $\bar{X}_p$ quality with an acceptable tail area P_t . In nine cases out of ten, the producer will be rejecting samples if the quality is no better than the lot tolerance average. If the quality is better than $\bar{X}_p$ ($\bar{X}_p$ shifted to the right), the area P_c becomes greater than 10%, which means the probability of acceptance becomes higher and vice versa. If the process remains fixed, and a lower consumer's risk is desired, a larger tail area, P_t will have to be accepted. This can be observed by referring to Fig. 5.19 and imagining the distribution shifted to the left to reduce area P_c which automatically increases area P_t . For a fixed consumer's risk of 10%, the process minimum may be lowered by taking larger sample sizes without increasing P_t or changing the process average. It should be noted that if $\bar{X}_p$, σ , P_t and P_c are fixed, the process minimum will approach $\bar{X}_p$ as a limit as the sample size increases. But by decreasing σ the process minimum approaches the specification minimum as a limit, P_c , P_t and n remaining constant. So far as production is concerned, low process minimums are desirable. The most efficient way of accomplishing this is to reduce the variability or standard deviation.

In summarizing, the following points should be clear.

The process minimum can be reduced when:

1. P_c , P_t , $\bar{X}_p$ and n are fixed by reducing σ (process minimum approaches specification minimum as a limit).
2. P_c , P_t , $\bar{X}_p$ and σ are fixed by increasing sample size (process minimum approaches lot tolerance average as a limit).

The tail area P can be reduced when:

1. P_c , n and $\bar{X}_p$ are fixed by decreasing σ .
2. P_c , n and σ are fixed by increasing $\bar{X}_p$.

The following data serve to illustrate the collection of daily random test samples and the method of plotting on a control chart. These data represent tension-shear test data on stainless steel, 0.055-in. thick annealed sheet type 302, and are displayed in Table 5.1.

Table 5.1—Tension-Shear Test Data, 0.055-In. Annealed Type 302 Stainless Steel

Spec. No.	Group No.									
	1	2	3	4	5	6	7	8	9	10
1	2,210	2,300	2,250	2,400	2,500	2,500	2,400	2,000	2,200	2,300
2	2,140	2,100	2,100	2,350	2,200	2,300	2,350	1,800	2,150	2,100
3	2,100	2,210	2,220	2,100	2,150	2,450	2,350	1,710	2,120	2,120
4	2,200	2,300	2,150	2,100	2,110	2,400	2,210	1,750	2,000	2,120
5	2,130	2,100	2,050	2,100	2,200	2,300	2,200	1,600	1,900	2,100
Sum of 5	10,780	11,010	10,770	11,050	11,160	12,050	11,510	8,860	10,370	10,740
$\bar{X}$ = Av. of 5	2,156	2,202	2,154	2,210	2,232	2,410	2,302	1,772	2,074	2,148
Max. =	2,210	2,300	2,250	2,400	2,500	2,500	2,400	2,000	2,200	2,300
Min. =	2,100	2,100	2,050	2,100	2,110	2,300	2,200	1,600	1,900	2,100
Range =	110	200	200	300	390	200	200	400	300	200
Squares of in-dividual values										
1	4,884,100	5,290,000	5,062,500	5,760,000	6,250,000	6,250,000	5,760,000	4,000,000	4,840,000	5,290,000
2	4,579,600	4,410,000	4,410,000	5,522,500	4,840,000	5,760,000	5,522,500	3,240,000	4,622,500	4,410,000
3	4,410,000	4,884,100	4,928,400	4,410,000	4,622,500	6,002,500	5,522,500	2,924,100	4,494,400	4,494,400
4	4,840,000	5,290,000	4,622,500	4,410,000	4,452,100	5,760,000	4,884,100	3,062,500	4,000,000	4,494,400
5	4,536,900	4,410,000	4,202,500	4,410,000	4,840,000	5,290,000	4,840,000	2,560,000	3,610,000	4,410,000
Total of Sqs.	23,250,600	24,284,160	23,223,900	24,512,500	25,004,600	29,062,500	26,529,100	15,788,600	21,566,900	23,098,800
Av. Sqs.	4,650,120	4,856,820	4,644,780	4,902,500	5,000,920	5,812,500	5,305,820	3,157,320	4,313,380	4,619,760
$(\bar{X})^2$ = Sq. of Av.	4,648,336	4,848,804	4,639,716	4,884,100	4,981,824	5,808,100	5,299,204	3,139,984	4,301,476	4,613,904
Diff. of Sqs.	1,784	8,016	5,464	18,400	19,096	4,400	6,616	7,336	11,904	5,856
$\sqrt{\text{Diff.}} = \sigma$	42	89	74	136	138	67	81	86	109	76

Calculations (based on data taken from Table 5.1) are shown below; these are the figures actually used in setting up the control charts of Fig. 5.18.

To compare the consistency of production between different conditions, as for various material strengths, compositions or thicknesses

Group No.	Group Av.	Range	σ
1	2,157	110	42
2	2,202	200	89
3	2,154	200	74
4	2,210	300	136
5	2,232	390	138
6	2,410	200	67
7	2,302	200	81
8	1,772	400	86
9	2,074	300	109
10	2,148	200	76
Total =	21,660	2560	896

Grand Av. $\bar{X} = 21,660 \div 10 = 2166$

$\bar{R} = 2560 \div 10 = 256$

$\bar{\sigma} = 896 \div 10 = 89.6 = 90$

Limits* = $\bar{X} \pm A\bar{\sigma} = 2166 \pm (1.596 \times 90) = 2022$ (min.) or 2310 (max.)

Range

Lower Limit = 0

Upper Limit* = $D_4\bar{R} = 256 \times 2.114 = 541.2$

wherein the individual group averages, and consequently the calculated standard deviations, are expected to be different, it is convenient to use the coefficient of variation. This is simply the standard deviation divided by the group average and usually expressed as a percentage.

These curves (Fig. 5.18) show that samples 6 and 8 were out of control, but that conditions were corrected on succeeding samples. The range appears quite broad, but this is due to the use of a relatively small sample for establishing limits, and also that two of the 10 groups are so far out of control.

The following references have been freely used in making the above-suggested procedure for statistical control of spot welding:

1. Clark, N. C., "Quality Control in Aircraft Spot Welding", *The Welding Journal* 23 (1), 48-59 (1944).
2. Robinson, H., "Determination by Statistical Analysis of Process Minimums for Spot Welding", *Ibid.*, 24 (5), 455-461 (1945).
3. American Society for Testing and Materials, *Manual on Quality Control*, STP-15C, Part 3.
4. American Standards Association, Standard Z1.1, (1958) *Guide for Quality Control*; also Standard Z1.2 (1958) *Control Chart Method of Analyzing Data*; also Standard Z1.3 (1958) *Control Chart Method of Controlling Quality During Production*.
5. American Welding Society, *Welding Handbook*, Fifth Edition, Section 3, Chapter 57, "Statistical Control of Weld Quality".

* ASTM *Manual on Quality Control*, STP-15C, Part 3, Section 11.

508. FORMS FOR RESISTANCE WELDING DATA SHEETS**508.1 General**

The forms shown in Figs. 5.20 (a), (b) and (c) are useful in maintaining data on resistance welding procedures both for control purposes and for future reference. It is hoped that the adoption of a standard form will assist in the comparison and correlation of data for additional recommended practices and revision to those already issued. The subjects which should be included in a resistance welding procedure are listed below. Supplementary sheets attached to the form sheet should be used for such amplified discussion of any of the details as may be necessary.

508.2 Subject

Type of welding, i.e., spot, seam, projection, etc. Kind of material, i.e., low-carbon steel, etc. Size of parts—thickness of stock, shape, etc.

508.3 Equipment

Type of welding machine—serial number. Number and rating of transformer. Identification of machine control.

508.4 Impedance

Data, if available.

508.5 Sketch

If shape of parts is not clearly expressed in subject, try to clarify same by sketch.

Always include dimensioned sketch of projections in projection welding.

Include sketch of any special welding edge preparations.

Include sketch of electrode positions if not standard.

508.6 Schedule

See form for type of welding used.

508.7 Discussion

(a) Indicate the type of weld desired. Include strength, appearance, tolerance of parts, if this is a factor.

(b) Report how closely the experimental welding approaches the desired weld. When speaking of strength include the manner of testing, together with results, such as shear or tensile machine, etc., or hammer and chisel test noting how weld broke, etc.

(c) Report any difficulties encountered in welding technique such as necessity for surface preparation of stock, spitting, deformation of parts or electrodes. If time of welding current is extremely critical, note same. Same applies to any other variable.

(d) If metallurgical examination is made, give details of findings. If defects are discovered, try to give relative importance by referring back to physical tests.

(e) If results are inconsistent or if job is not satisfactorily weldable, report same with evidence of why such a conclusion is made. If possible

the physical test values showing inconsistency should be noted so that relative degree of inconsistency can be judged.

(f) If it is not already evident, note any factors which may produce

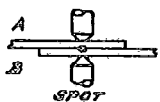
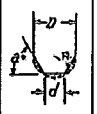
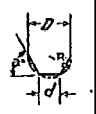
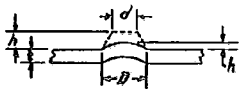
RESISTANCE WELDING DATA SHEET				
EQUIPMENT IDENTIFICATION _____				
TYPE _____ SERIAL _____				
TRANSFORMER NO. _____ RATING _____				
CONTROL _____				
				
MATERIAL	Thickness	SIDE A	SIDE B	Weld Current
	Approx. Analysis (type)			S.C. Current
	Surface Cond.			Tap and/or Phase Setting
	Ultimate Strength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

Fig. 5.20 (a) – Form for Resistance Welding Data Sheet for Spot and Projection Welding

(See Par. 508)

production difficulties. This is a guide to the engineering department in the design of fixtures, electrodes and general machine operation.

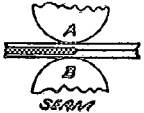
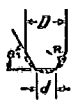
RESISTANCE WELDING DATA SHEET				
EQUIPMENT IDENTIFICATION				
TYPE _____		SERIAL _____		
TRANSFORMER NO. _____		RATING _____		
CONTROL _____				
				
MATERIAL	Thickness	SIDE A	SIDE B	Weld Current
	Approx. Analysis (type)			S.C. Current
				Tap and/or Phase Setting
	Surface Cond.			Throat Opening
	Ult. Strength			Throat Spacing
	Yield Strength			Synchronous or non-synchronous timing
	Elongation %			Heat Time
	Red. in Area %			Cool Time
ELECTRODE	Hardness			Electrode Force
	Material			Tension Shear Test
ELECTRODE	Shape			Tension Test
				TORSIONAL
SEAM	Roll Speed Inches per Min.	Indentation		
	Spots per Inch	Other Tests:		
	Width of Weld			
MASH	Overlap or filler			
	Length of Weld			
Remarks:				Photos

Fig. 5.20 (b) — Form for Resistance Welding Data Sheet for Seam Welding
(See Par. 508)

RESISTANCE WELDING DATA SHEET FOR FLASH OR UPSET WELDING

MACHINE DESCRIPTION _____

MFGR. _____

KVA _____ SERIAL _____

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

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

COMMENTS: _____

PLATEN TRAVEL INFORMATION _____

TESTING METHODS

Tension _____

"U" Bend Test _____

Hardness _____

Macro _____

REMARKS:

Fig. 5.20 (c) – Form for Resistance Welding Data Sheet for Flash or Upset Welding