

# **Recommended Practices for Resistance Welding**



**Documents**

Document Sharing Hub

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

**Approved by**  
**the American National Standards Institute**  
**January 25, 2019**

# **Recommended Practices for Resistance Welding**

**6th Edition**

**Supersedes AWS C1.1M/C1.1:2012**

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

Under the Direction of the  
AWS Technical Activities Committee

Approved by the  
AWS Board of Directors

## **Abstract**

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

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



ISBN Print: 978–1–64322–028–4

ISBN PDF: 978–1–64322–029–1

©2019 by American Welding Society

All rights reserved

Printed in the United States of America

**Photocopy Rights.** No portion of this standard may be reproduced, stored in a retrieval system, or transmitted in any form, including mechanical, photocopying, recording, or otherwise, without the prior written permission of the copyright owner.

Authorization to photocopy items for internal, personal, or educational classroom use only or the internal, personal, or educational classroom use only of specific clients is granted by the American Welding Society provided that the appropriate fee is paid to the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, tel: (978) 750–8400; Internet: [www.copyright.com](http://www.copyright.com).

## Statement on the Use of American Welding Society Standards

All standards (codes, specifications, recommended practices, methods, classifications, and guides) of the American Welding Society (AWS) are voluntary consensus standards that have been developed in accordance with the rules of the American National Standards Institute (ANSI). When AWS American National Standards are either incorporated in, or made part of, documents that are included in federal or state laws and regulations, or the regulations of other governmental bodies, their provisions carry the full legal authority of the statute. In such cases, any changes in those AWS standards must be approved by the governmental body having statutory jurisdiction before they can become a part of those laws and regulations. In all cases, these standards carry the full legal authority of the contract or other document that invokes the AWS standards. Where this contractual relationship exists, changes in or deviations from requirements of an AWS standard must be by agreement between the contracting parties.

AWS American National Standards are developed through a consensus standards development process that brings together volunteers representing varied viewpoints and interests to achieve consensus. While AWS administers the process and establishes rules to promote fairness in the development of consensus, it does not independently test, evaluate, or verify the accuracy of any information or the soundness of any judgments contained in its standards.

AWS disclaims liability for any injury to persons or to property, or other damages of any nature whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from the publication, use of, or reliance on this standard. AWS also makes no guarantee or warranty as to the accuracy or completeness of any information published herein.

In issuing and making this standard available, AWS is neither undertaking to render professional or other services for or on behalf of any person or entity, nor is AWS undertaking to perform any duty owed by any person or entity to someone else. Anyone using these documents should rely on his or her own independent judgment or, as appropriate, seek the advice of a competent professional in determining the exercise of reasonable care in any given circumstances. It is assumed that the use of this standard and its provisions is entrusted to appropriately qualified and competent personnel.

This standard may be superseded by new editions. This standard may also be corrected through publication of amendments or errata, or supplemented by publication of addenda. Information on the latest editions of AWS standards including amendments, errata, and addenda is posted on the AWS web page ([www.aws.org](http://www.aws.org)). Users should ensure that they have the latest edition, amendments, errata, and addenda.

Publication of this standard does not authorize infringement of any patent or trade name. Users of this standard accept any and all liabilities for infringement of any patent or trade name items. AWS disclaims liability for the infringement of any patent or product trade name resulting from the use of this standard.

AWS does not monitor, police, or enforce compliance with this standard, nor does it have the power to do so.

Official interpretations of any of the technical requirements of this standard may only be obtained by sending a request, in writing, to the appropriate technical committee. Such requests should be addressed to the American Welding Society, Attention: Managing Director, Standards Development, 8669 NW 36 St, # 130, Miami, FL 33166 (see Annex B). With regard to technical inquiries made concerning AWS standards, oral opinions on AWS standards may be rendered. These opinions are offered solely as a convenience to users of this standard, and they do not constitute professional advice. Such opinions represent only the personal opinions of the particular individuals giving them. These individuals do not speak on behalf of AWS, nor do these oral opinions constitute official or unofficial opinions or interpretations of AWS. In addition, oral opinions are informal and should not be used as a substitute for an official interpretation.

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

This page is intentionally blank.

# Personnel

## AWS C1 Committee on Resistance Welding

|                          |                                       |
|--------------------------|---------------------------------------|
| B. Kelly, Chair          | <i>Kelly Welding Solutions PC</i>     |
| W. F. Qualls, Vice Chair | <i>Consultant</i>                     |
| M. Diaz, Secretary       | <i>American Welding Society</i>       |
| T. W. Alexander          | <i>Centerline (Windsor) Ltd.</i>      |
| W. H. Brafford           | <i>Consultant</i>                     |
| R. K. Cohen              | <i>Weld Computer Corporation</i>      |
| M. Cubert                | <i>Space Exploration Technologies</i> |
| R. Michelena             | <i>T. J. Snow Company, Inc.</i>       |
| D. Wellman               | <i>Obara Corporation</i>              |

## Advisors to the AWS C1 Committee on Resistance Welding

|                 |                                     |
|-----------------|-------------------------------------|
| B. J. Bastian   | <i>Benmar Associates</i>            |
| K. Hofman       | <i>Roman Engineering Services</i>   |
| M. Kimchi       | <i>Edison Welding Institute</i>     |
| D. F. Maatz     | <i>R&amp;E Engineering Services</i> |
| N. S. Scotchmer | <i>Huys Industries Limited</i>      |
| D. C. Sorenson  | <i>Entron Controls, LLC</i>         |
| M. Tumuluru     | <i>U.S. Steel</i>                   |

This page is intentionally blank.

## Foreword

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

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

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

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

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

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

This page is intentionally blank.

# Table of Contents

|                                                                              | Page No.  |
|------------------------------------------------------------------------------|-----------|
| <i>Personnel</i> .....                                                       | v         |
| <i>Foreword</i> .....                                                        | vii       |
| <i>List of Tables</i> .....                                                  | xi        |
| <i>List of Figures</i> .....                                                 | xiii      |
| <b>1. General Requirements</b> .....                                         | <b>1</b>  |
| 1.1 Scope .....                                                              | 1         |
| 1.2 Units of Measurement .....                                               | 1         |
| 1.3 Safety .....                                                             | 1         |
| <b>2. Normative References</b> .....                                         | <b>2</b>  |
| <b>3. Terms and Definitions</b> .....                                        | <b>2</b>  |
| <b>4. Resistance Spot and Seam Welding</b> .....                             | <b>3</b>  |
| 4.1 Uncoated Carbon and Low-Alloy Steels .....                               | 3         |
| 4.2 Coated Carbon and Low-Alloy Steels .....                                 | 12        |
| 4.3 Aluminum Alloys .....                                                    | 14        |
| 4.4 Stainless Steels, Nickel, Nickel-Base, and Cobalt-Base Alloys .....      | 20        |
| 4.5 Copper and Copper Alloys .....                                           | 23        |
| 4.6 Titanium and Titanium Alloys .....                                       | 23        |
| 4.7 Welding Data Comments and Discussions Applicable to Various Metals ..... | 27        |
| 4.8 Weld Discrepancies and Causes .....                                      | 46        |
| 4.9 Weld Quality and Mechanical Property Tests .....                         | 48        |
| <b>5. Projection Welding</b> .....                                           | <b>70</b> |
| 5.1 Introduction .....                                                       | 70        |
| 5.2 Embossed Projection Welding .....                                        | 72        |
| 5.3 Solid Projection Welding .....                                           | 78        |
| 5.4 Multiple Projection Welding .....                                        | 80        |
| 5.5 Weld Quality and Mechanical Property Tests .....                         | 80        |
| <b>6. Flash Welding</b> .....                                                | <b>80</b> |
| 6.1 Introduction .....                                                       | 80        |
| 6.2 Equipment .....                                                          | 81        |
| 6.3 Welding Variables .....                                                  | 85        |
| 6.4 Welding Variable Measurements .....                                      | 88        |
| 6.5 Classification of Steels for Flash Welding .....                         | 89        |
| 6.6 Joint Preparation and Cleaning .....                                     | 89        |
| 6.7 Welding Schedules .....                                                  | 91        |
| 6.8 Weld Discrepancies and Causes .....                                      | 91        |
| 6.9 Weld Quality and Mechanical Property Tests .....                         | 94        |
| <b>7. Upset Welding</b> .....                                                | <b>95</b> |
| 7.1 Introduction .....                                                       | 95        |
| 7.2 Equipment .....                                                          | 95        |
| 7.3 Welding Variables .....                                                  | 95        |
| 7.4 Joint Preparation and Cleaning .....                                     | 95        |

7.5 Welding Parameters .....95

7.6 Weld Quality and Mechanical Property Tests .....95

8. **Weld Bonding.** .....96

8.1 Introduction .....96

8.2 Aluminum Alloys .....96

8.3 Other Metals.....97

8.4 Weld Bonding Quality and Mechanical Property Tests .....99

9. **Equipment Monitoring and Maintenance.** .....100

Annex A (Informative)—Informative References .....111

Annex B (Informative)—Requesting an Official Interpretation on an AWS Standard .....113

List of AWS C1 Documents for Resistance Welding .....115

# List of Tables

| Table | Page No.                                                                                                                                       |
|-------|------------------------------------------------------------------------------------------------------------------------------------------------|
| 1     | Spot-Welding Parameters for Bare, Galvanneal, and Galvanized Low-Carbon Steel<br><350 MPa [72 ksi] Ultimate Tensile Strength . . . . .5        |
| 2     | Pulsation Spot-Welding Parameters for Low-Carbon Steel . . . . .6                                                                              |
| 3     | Seam—Welding Parameters for Bare, Galvanneal, and Galvanized Low-Carbon Steel<br>>300 MPa [44 ksi] Ultimate Tensile Strength . . . . .7        |
| 4     | Spot-Welding Parameters for Bare, Galvanneal, and Galvanized Low-Carbon Steel<br>350–700 MPa [50–100 ksi] Ultimate Tensile Strength . . . . .8 |
| 5     | Spot-Welding Parameters for Bare, Galvanneal, and Galvanized Low-Carbon Steel<br>>700 MPa [<101 ksi] Ultimate Tensile Strength . . . . .9      |
| 6     | Spot-Welding Parameters for Low-Alloy and Medium-Carbon Steels . . . . .10                                                                     |
| 7     | Electrode Materials for Resistance Welding . . . . .11                                                                                         |
| 8     | Basic Aluminum Alloy Groups . . . . .15                                                                                                        |
| 9     | Resistance Weldability Chart for Commonly Used Combinations of Aluminum Alloys<br>(Based On Equal Thickness) . . . . .16                       |
| 10    | Recommended Spot-Weld Spacing, Edge Distance, Overlap, and Distance between Rows of<br>Welds for Aluminum and Its Alloys . . . . .19           |
| 11    | Spot-Welding Parameters for Aluminum Alloys on Standard Single-Phase A-C Type Equipment . . . . .20                                            |
| 12    | Spot-Welding Parameters for Aluminum Alloys on Single-Phase A-C Slope Control<br>Type Machines . . . . .21                                     |
| 13    | Spot-Welding Parameters for Aluminum Alloys on Three-Phase Rectifier-Type Equipment . . . . .22                                                |
| 14    | Spot-Welding Parameters for Aluminum Alloys on Three-Phase Frequency Converter-Type<br>Equipment (Single Impulse Welds) . . . . .24            |
| 15    | Spot-Welding Parameters for Stainless Steels . . . . .25                                                                                       |
| 16    | Pulsation Spot-Welding Parameters for Stainless Steels . . . . .26                                                                             |
| 17    | Seam-Welding Parameters for Stainless Steels . . . . .27                                                                                       |
| 18    | Spot-Welding Parameters for Annealed Nickel–Copper Alloy on Single-Phase Equipment . . . . .28                                                 |
| 19    | Spot-Welding Parameters for Annealed Nickel–Copper Alloy on Three-Phase Frequency<br>Converter Machines . . . . .29                            |
| 20    | Seam-Welding Parameters for Annealed Nickel–Copper Alloy on Single-Phase Equipment . . . . .30                                                 |
| 21    | Seam-Welding Parameters for Annealed Nickel–Copper Alloy on Three-Phase Frequency<br>Converter Machines . . . . .33                            |
| 22    | Spot-Welding Parameters for Annealed Nickel–Chromium Alloy 600 on Single-Phase Equipment . . . . .34                                           |
| 23    | Spot-Welding Parameters for Annealed Nickel–Chromium Alloy X750 on Single-Phase<br>Equipment . . . . .35                                       |
| 24    | Spot-Welding Parameters for Annealed Nickel–Chromium Alloy X750 on Three-Phase<br>Frequency Converter Machines . . . . .36                     |
| 25    | Spot-Welding Parameters for Annealed Nickel–Chromium Alloy X750 on Three-Phase<br>Dry Disk Rectifier Machines . . . . .37                      |
| 26    | Seam-Welding Parameters for Annealed Nickel–Chromium Alloy X750 on Single-Phase<br>Equipment . . . . .38                                       |
| 27    | Seam-Welding Parameters for Annealed Nickel–Chromium Alloy X750 on Three-Phase<br>Frequency Converter Machines . . . . .39                     |
| 28    | Roll-Spot-Welding Parameters for Annealed Nickel–Chromium Alloy X750 on Three-Phase<br>Dry Disk Rectifier Machines . . . . .40                 |
| 29    | Spot-Welding Parameters for Annealed Nickel on Single-Phase Equipment . . . . .41                                                              |

|    |                                                                                                                                             |     |
|----|---------------------------------------------------------------------------------------------------------------------------------------------|-----|
| 30 | Spot-Welding Parameters for Nickel–Iron–Chromium Alloys . . . . .                                                                           | 42  |
| 31 | Seam-Welding Parameters for Nickel–Iron–Chromium Alloys. . . . .                                                                            | 42  |
| 32 | Seam-Welding Parameters for Cobalt–Chromium–Nickel Alloys. . . . .                                                                          | 42  |
| 33 | Spot-Welding Parameters for Various Copper Alloys . . . . .                                                                                 | 43  |
| 34 | Spot-Welding Parameters for Titanium Alloy 6% Al–4% V . . . . .                                                                             | 43  |
| 35 | Variation of Current Density and Unit Force Due to Lack of Electrode Tip Maintenance . . . . .                                              | 44  |
| 36 | Spot-Welding Parameters for Various Thickness Combinations and Arrangements of<br>Uncoated and Coated-Carbon and Low-Alloy Steels . . . . . | 45  |
| 37 | Projection and Die Geometries for Welding a Range of Heavy-Gauge Steels . . . . .                                                           | 73  |
| 38 | Process Requirements for Projection Welding a Range of Heavy-Gauge Steels. . . . .                                                          | 74  |
| 39 | Punch Design Data for Low-Carbon Steel Projections . . . . .                                                                                | 75  |
| 40 | Die Button Design Data for Low-Carbon Steel Projections . . . . .                                                                           | 76  |
| 41 | Punch and Die Design Data for Forming Projections on Stainless Steel. . . . .                                                               | 77  |
| 42 | Projection Welding Parameters for Low-Carbon Steel . . . . .                                                                                | 78  |
| 43 | Projection Welding Parameters for Galvanized Low-Carbon Steel. . . . .                                                                      | 78  |
| 44 | Projection Welding Parameters for Stainless Steels. . . . .                                                                                 | 79  |
| 45 | Projection Designs and Process Requirements for Annular Projection Welding Some<br>Representative Light-Gauge Steels . . . . .              | 79  |
| 46 | Projection Welding Design Data for Stainless Steels. . . . .                                                                                | 82  |
| 47 | Embossed Projections for Low-Carbon Steel . . . . .                                                                                         | 83  |
| 48 | Process Requirements for Cross-Wire Welding a Range of Thicknesses of Hot- and<br>Cold-Drawn Steel Wires . . . . .                          | 84  |
| 49 | Data for Flash Welding of Tubing and Flat Sheets . . . . .                                                                                  | 92  |
| 50 | Data for Flash Welding of Solid Round, Hex, Square, and Rectangular Bars. . . . .                                                           | 93  |
| 51 | Weld-Bonding Surface Preparation for Aluminum Alloys by Low-Voltage Anodizing . . . . .                                                     | 97  |
| 52 | Comparison between Resistance Spot-Welding and Weld-Bonding of Aluminum Alloys . . . . .                                                    | 98  |
| 53 | Typical Spot-Welding Parameters for 1.6 mm [0.063 in] Thick 7075-T6 Aluminum Treated<br>with a Low-Voltage Anodizing Process. . . . .       | 98  |
| 54 | Commonly Used Metric Conversions Inch-Millimeter Conversion . . . . .                                                                       | 99  |
| 55 | <u>Spot-Welding Parameters for Uncoated AHSS Using AC Welding Machine for IISI Group 3<br/>And 4 Steels . . . . .</u>                       | 109 |
| 56 | <u>Spot-Welding Parameters for Coated AHSS Using AC Welding Machine for IISI Group 3<br/>And 4 Steels . . . . .</u>                         | 109 |
| 57 | <u>Spot-Welding Parameters for Uncoated AHSS Using MFDC Welding Machine for IISI Group 3<br/>And 4 Steels . . . . .</u>                     | 110 |
| 58 | <u>Spot-Welding Parameters for Coated AHSS Using MFDC Welding Machine for IISI Group 3<br/>And 4 Steels . . . . .</u>                       | 110 |

# List of Figures

| Figure | Page No.                                                                                                                               |
|--------|----------------------------------------------------------------------------------------------------------------------------------------|
| 1      | Coring in Nickel Alloy 718 (UNS N07718) Resistance Seam Weld, 200X . . . . . 23                                                        |
| 2      | Standard RWMA Nose or Tip Geometries of Spot-Welding Electrodes . . . . . 31                                                           |
| 3      | ISO 5821 Female Electrode Cap Designations . . . . . 32                                                                                |
| 4      | Peel Test . . . . . 50                                                                                                                 |
| 5      | Peel Test Specimens . . . . . 51                                                                                                       |
| 6      | Measurement of a Weld Button Resulting from the Peel Test . . . . . 52                                                                 |
| 7      | Fracture or Pullout Modes of Weld Buttons . . . . . 52                                                                                 |
| 8      | Bend Test Specimen . . . . . 53                                                                                                        |
| 9      | Chisel . . . . . 54                                                                                                                    |
| 10     | Tension-Shear Test Specimen . . . . . 55                                                                                               |
| 11     | Spot Welds in Sheet . . . . . 56                                                                                                       |
| 12     | Twisting Angle $\gamma$ at Fracture in Tension Shear Test . . . . . 56                                                                 |
| 13     | Cross-Tension Test Specimens . . . . . 58                                                                                              |
| 14     | Fixture for Cross-Tension Test (for Thicknesses up to 4.8 mm [0.19 in]) . . . . . 59                                                   |
| 15     | Fixture for Cross-Tension Test (for Thicknesses 4.8 mm [0.19 in] and Over) . . . . . 60                                                |
| 16     | U-Test Specimen . . . . . 61                                                                                                           |
| 17     | U-Tension Test Jig . . . . . 62                                                                                                        |
| 18a    | <u>Pull Test (90-Degree Peel Test)—Single Weld</u> . . . . . 62                                                                        |
| 18b    | <u>Pull Test (90-Degree Peel Test)—Dual Weld</u> . . . . . 63                                                                          |
| 19     | Test Specimen and Typical Equipment for Torsion-Shear Test . . . . . 64                                                                |
| 20     | Drop-Impact Test Specimen . . . . . 66                                                                                                 |
| 21     | Drop-Impact Test Machine . . . . . 67                                                                                                  |
| 22     | Test Fixture for Shear-Impact Loading Test . . . . . 67                                                                                |
| 23     | Test Fixture for Tension-Impact Loading Test . . . . . 68                                                                              |
| 24     | Fatigue Testing Machine . . . . . 69                                                                                                   |
| 25     | Pillow Test for Seam Welds . . . . . 70                                                                                                |
| 26     | Typical Stack-up Configuration for Embossed Projection Welding of Sheet . . . . . 71                                                   |
| 27     | Typical Configuration for Solid Projection Welding . . . . . 71                                                                        |
| 28     | Diagram Defining How Set-Down is Estimated on Cross-Wire Welds . . . . . 80                                                            |
| 29     | Characteristics of Projection Collapse during Annular Projection Welding with Different<br>Base-Projection Widths . . . . . 81         |
| 30     | Chart of Flash Welding Definitions . . . . . 86                                                                                        |
| 31     | Chart of Flash Welding Definitions . . . . . 87                                                                                        |
| 32     | Flash Welding of Tubing and Flat Sheets . . . . . 90                                                                                   |
| 33     | Flash Welding of Solid Round, Hex, Square, and Rectangular Bars . . . . . 90                                                           |
| 34     | Comparison of Tensile-Shear Strengths of Uncured and Cured (Single Spot) Weld-Bonded<br>Joints of 7075-T6 Aluminum Alloy . . . . . 100 |
| 35     | Comparison of Fatigue Test Results of Weld-Bonded and Adhesive-Bonded Joints of<br>7075-T6 Aluminum Alloy . . . . . 101                |
| 36     | Fatigue Test Specimen of Weld-Bonded and Adhesive-Bonded Joints . . . . . 102                                                          |
| 37     | Form for Resistance Welding Data Sheet for Spot and Projection Welding . . . . . 106                                                   |
| 38     | Form for Resistance Welding Data Sheet for Seam Welding . . . . . 107                                                                  |
| 39     | Form for Resistance Welding Data Sheet for Flash or Upset Welding . . . . . 108                                                        |

This page is intentionally blank.

# Recommended Practices for Resistance Welding

## 1. General Requirements

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

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

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

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

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

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

Safety and health information is available from the following sources:

American Welding Society:

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

AWS Safety and Health Fact Sheets; and

Other safety and health information on the AWS website.

Material or Equipment Manufacturers:

Safety Data Sheets supplied by materials manufacturers

Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies:

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

## 2. Normative References

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

### AWS standards:

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

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

## 3. Terms and Definitions

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

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

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

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

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

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

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

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

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

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

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

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

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

## 4. Resistance Spot and Seam Welding

### 4.1 Uncoated Carbon and Low-Alloy Steels

#### 4.1.1 Introduction

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

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

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

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

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

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

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

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

**4.1.1.5 AHSS.** Advanced High Strength Steels (AHSS) is a family of HSS introduced since the early 2000s for various automotive applications. These steels differ from HSLA steels; they do not necessarily contain microalloying

elements. Instead, the required strength and ductility are achieved through a combination of additional major alloying elements (such as manganese, chromium, molybdenum) and precise control of the steel microstructure. AHSS grades have a minimum tensile strength of 500 MPa [72 ksi] and are commercially available from 500 to 1000 MPa [72–145 ksi]. AHSS grades include Dual Phase (DP) and Transformation-Induced Plasticity (TRIP) steels. The steels are available both in coated and uncoated conditions. Steels with minimum tensile strength up to 1000 MPa [145 ksi] have shown to be readily weldable without pre or postweld heating. Tables 55 and 56 provide starting spot-weld parameters for AC welding machines, while Tables 57 and 58 provide the parameters for MFDC welding machines.

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

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

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

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

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

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

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

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

<sup>a</sup> Use of coated parameters recommended with the presence of a coating at any faying surface.

<sup>b</sup> These recommendations are based on available weld schedules representing recommendations from resistance welding equipment suppliers and users.

<sup>c</sup> For intermediate thicknesses parameters may be interpolated.

<sup>d</sup> Minimum weld button shear strength determined as follows:

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

ST = Shear Tension Strength (kN)

S = Base Metal Tensile Strength (MPa)

t = Material Thickness (mm)

<sup>e</sup> Metal thicknesses represent the actual thickness of the sheets being welded. In the case of welding two sheets of different thicknesses, use the welding parameters for the thinner sheet.

<sup>f</sup> Welding parameters are applicable when using electrode materials included in RWMA classes 1, 2, and 20.

<sup>g</sup> Electrode shapes listed include: A-pointed, B-domed, E-truncated, F-radiused. Figure 2 shows these shapes.

– The use of Type-B geometry may require a reduction in current and may result in excessive indentation unless face is dressed to specified diameter.

– The use of Type-F geometry may require an increase in current.

<sup>h</sup> Cycle times shown apply to AC 60 Hz equipment. For 50 Hz equipment, multiply the weld times shown in cycles by 0.83, then round down to the nearest whole number.

<sup>i</sup> For DC welding equipment, lower current settings may be appropriate.

<sup>j</sup> Nugget diameters are listed as:

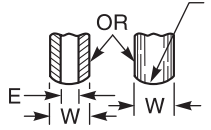
– the minimum diameter that is recommended to be considered a satisfactory weld.

– the initial aim setup nugget diameter that is recommended in setting-up a weld station to produce nuggets that consistently surpass the satisfactory weld nugget diameter for a given number of production welds.

**Table 2**  
**Pulsation Spot-Welding Parameters for Low-Carbon Steel<sup>a, b</sup>**

| Combination<br>of<br>Thicknesses<br>to be Welded<br>mm [in] | Weld Time <sup>f</sup>                       |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|-------------------------------------------------------------|----------------------------------------------|-----------------------------|-------------------------------------|----------------------|--|-----------------------|-------------|--|--|----------------------------|------------------------------------------|-----------------------------------------|-------------------------------|-------|
|                                                             | Electrode Diameter <sup>c</sup><br>and Shape |                             | Net<br>Electrode<br>Force<br>N [lb] | On                   |  |                       | Off         |  |  | Current<br>Approx.<br>Amps | Minimum<br>Contact<br>Overlap<br>mm [in] | Minimum<br>Shear<br>Strength<br>kN [lb] | Nugget<br>Diameter<br>mm [in] |       |
|                                                             |                                              |                             |                                     | 20 [333]             |  |                       | 5 [83]      |  |  |                            |                                          |                                         | Minimum<br>Satisfactory       | Setup |
|                                                             |                                              |                             |                                     | Cycles [ms]          |  |                       | Cycles [ms] |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     | Number of Pulsations |  |                       |             |  |  |                            |                                          |                                         |                               |       |
| Single<br>Welds                                             |                                              | Adjacent Welds <sup>g</sup> |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     | 25–51 mm<br>[1–2 in] |  | 51–102 mm<br>[2–4 in] |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |
|                                                             |                                              |                             |                                     |                      |  |                       |             |  |  |                            |                                          |                                         |                               |       |

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

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

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

<sup>a</sup> Use of coated parameters recommended with the presence of a coating at any faying surface.

<sup>b</sup> Material should be free from scale, oxides, paint, grease, and oil.

<sup>c</sup> For DC welding equipment, lower current settings may be appropriate.

<sup>d</sup> For the electrodes with a radius face, the face width is the same as the electrode width.

<sup>e</sup> Electrode materials: RWMA Class 1, 2, and 20.

<sup>f</sup> Electrode widths are based on the following: ISO Standards 10, 13, 16, and 19 mm; RWMA Standards 0.38, 0.48(0.50), 0.63, 0.75, 0.88, and 1.00 in.

<sup>g</sup> Cycle times shown apply to AC 60 Hz equipment. For 50 Hz equipment, multiply the weld times shown in cycles by 0.83, then round down to the nearest whole number.

<sup>h</sup> Welding speeds noted do not give a leak-tight seam.

<sup>i</sup> For large assemblies, minimum contacting overlap indicated should be increased by 30 percent.

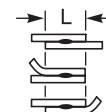


**Table 4**  
**Spot-Welding Parameters for Bare, Galvanneal, and Galvanized Low-Carbon Steel 350–700 MPa [50–108 ksi] Ultimate Tensile Strength<sup>a,b,c,d,e</sup>**

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

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

<sup>a</sup> Use of coated parameters recommended with the presence of a coating at any faying surface.

<sup>b</sup> These recommendations are based on available weld schedules representing recommendations from resistance welding equipment suppliers and users.

<sup>c</sup> For intermediate thicknesses parameters may be interpolated.

<sup>d</sup> Minimum weld button shear strength determined as follows:

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

ST = Shear Tension Strength (kN)

S = Base Metal Tensile Strength (MPa)

t = Material Thickness (mm)

<sup>e</sup> For DC welding equipment, lower current settings may be appropriate.

<sup>f</sup> Metal thicknesses represent the actual thickness of the sheets being welded. In the case of welding two sheets of different thicknesses, use the welding parameters for the thinner sheet.

<sup>g</sup> Welding parameters are applicable when using electrode materials included in RWMA classes 1, 2, and 20.

<sup>h</sup> Electrode shapes listed include: A-pointed, B-domed, E-truncated, F-radiused. Figure 2 shows these shapes.

– The use of Type-B geometry may require a reduction in current and may result in excessive indentation unless face is dressed to specified diameter.

– The use of Type-F geometry may require an increase in current.

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

<sup>j</sup> Nugget diameters are listed as:

– the minimum diameter that is recommended to be considered a satisfactory weld.

– the initial aim setup nugget diameter that is recommended in setting-up a weld station to produce nuggets that consistently surpass the satisfactory weld nugget diameter for a given number of production welds.

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

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

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

<sup>a</sup> Use of coated parameters recommended with the presence of a coating at any faying surface.

<sup>b</sup> These recommendations are based on available weld schedules representing recommendations from resistance welding equipment suppliers and users.

<sup>c</sup> For intermediate thicknesses parameters may be interpolated.

<sup>d</sup> Minimum weld button shear strength determined as follows:

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

ST = Shear Tension Strength (kN)

S = Base Metal Tensile Strength (MPa)

t = Material Thickness (mm)

<sup>e</sup> Nugget diameters are listed as:

– the minimum diameter that is recommended to be considered a satisfactory weld.

– the initial aim setup nugget diameter that is recommended in setting-up a weld station to produce nuggets that consistently surpass the satisfactory weld nugget diameter for a given number of production welds.

<sup>f</sup> Metal thicknesses represent the actual thickness of the sheets being welded. In the case of welding two sheets of different thicknesses, use the welding parameters for the thinner sheet.

<sup>g</sup> Welding parameters are applicable when using electrode materials included in RWMA classes 1, 2, and 20.

<sup>h</sup> Electrode shapes listed include: A-pointed, B-domed, E-truncated, F-radiused. Figure 2 shows these shapes.

– The use of Type-B geometry may require a reduction in current and may result in excessive indentation unless face is dressed to specified diameter.

– The use of Type-F geometry may require an increase in current.

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

<sup>j</sup> For DC welding equipment, lower current settings may be appropriate.

**Table 6**  
**Spot-Welding Parameters for Low-Alloy and Medium-Carbon Steels<sup>a,b</sup>**

| Material <sup>c</sup> |                       | Electrode <sup>d,e,f</sup> |                               |                               |                             | Net<br>Electrode<br>Weld and<br>Temper<br>Force kN [lb] | Weld <sup>b</sup> Time |     | Quench <sup>b</sup> Time |      | Temper <sup>b</sup> Time |      | Weld <sup>g</sup><br>Current<br>(Approx.)<br>Amps | Temper <sup>f</sup><br>Current<br>% of<br><u>Expulsion</u><br>Weld<br>Current | Minimum<br>Contacting<br>Overlap<br>mm [in] | Minimum <sup>h</sup><br>Weld<br>Spacing<br>mm [in] | Minimum<br>Shear<br>Strength<br>kN [lb] | Satisfactory<br>Nugget<br>Diameter<br>mm [in] |
|-----------------------|-----------------------|----------------------------|-------------------------------|-------------------------------|-----------------------------|---------------------------------------------------------|------------------------|-----|--------------------------|------|--------------------------|------|---------------------------------------------------|-------------------------------------------------------------------------------|---------------------------------------------|----------------------------------------------------|-----------------------------------------|-----------------------------------------------|
| Type                  | Condition             | Thickness<br>mm [in]       | D Min.<br>Diameter<br>mm [in] | d Face<br>Diameter<br>mm [in] | R Face<br>Radius<br>mm [in] |                                                         | Cycles                 | ms  | Cycles                   | ms   | Cycles                   | ms   |                                                   |                                                                               |                                             |                                                    |                                         |                                               |
| SAE 1020              | Hot rolled            | 1.02<br>[0.040]            | 16 [0.63]                     | 6.4 [0.25]                    | 150<br>[6.0]                | 6.56 [1470]                                             | 6                      | 100 | 17                       | 283  | 6                        | 100  | 16 000                                            | 90                                                                            | 13 [0.51]                                   | 25 [0.98]                                          | 6.05<br>[1360]                          | 5.8 [0.23]                                    |
| SAE 1035              | Hot rolled            | 1.02<br>[0.040]            | 16 [0.63]                     | 6.4 [0.25]                    | 150<br>[6.0]                | 6.56 [1470]                                             | 6                      | 100 | 20                       | 333  | 6                        | 100  | 14 200                                            | 91                                                                            | 13 [0.51]                                   | 25 [0.98]                                          | 6.94<br>[1560]                          | 5.6 [0.22]                                    |
| SAE 1045              | Hot rolled            | 1.02<br>[0.040]            | 16 [0.63]                     | 6.4 [0.25]                    | 150<br>[6.0]                | 6.56 [1470]                                             | 6                      | 100 | 24                       | 400  | 6                        | 100  | 13 800                                            | 88                                                                            | 13 [0.51]                                   | 25 [0.98]                                          | 8.90<br>[2000]                          | 5.3 [0.21]                                    |
| SAE 4130              | Hot rolled            | 1.02<br>[0.040]            | 16 [0.63]                     | 6.4 [0.25]                    | 150<br>[6.0]                | 6.56 [1470]                                             | 6                      | 100 | 18                       | 300  | 6                        | 100  | 13 000                                            | 90                                                                            | 13 [0.51]                                   | 25 [0.98]                                          | 9.43<br>[2120]                          | 5.6 [0.22]                                    |
| SAE 4340              | Normalized<br>& drawn | 0.79<br>[0.031]            | 16 [0.63]                     | 4.8 [0.19]                    | 150<br>[6.0]                | 4.00 [900]                                              | 4                      | 66  | 12                       | 200  | 4                        | 66   | 8 250                                             | 84                                                                            | 11 [0.43]                                   | 19 [0.75]                                          | 4.82<br>[1080]                          | 4.1 [0.16]                                    |
| SAE 4340              | Normalized<br>& drawn | 1.59<br>[0.062]            | 19 [0.75]                     | 7.9 [0.31]                    | 150<br>[6.0]                | 8.90 [2000]                                             | 10                     | 166 | 45                       | 750  | 10                       | 166  | 13 900                                            | 77                                                                            | 16 [0.63]                                   | 38 [1.50]                                          | 17.08<br>[3840]                         | 6.9 [0.27]                                    |
| SAE 4340              | Normalized<br>& drawn | 3.18<br>[0.125]            | 25 [1.00]                     | 15.9<br>[0.63]                | 254<br>[10.0]               | 24.47 [5500]                                            | 45                     | 750 | 240                      | 4000 | 90                       | 1500 | 21 800                                            | 86                                                                            | 22 [0.87]                                   | 64 [2.52]                                          | 60.9<br>[13680]                         | 14.0 [0.55]                                   |
| SAE 8630              | Normalized<br>& drawn | 0.79<br>[0.031]            | 13 [0.50]                     | 4.8 [0.19]                    | 150<br>[6.0]                | 3.56 [800]                                              | 4                      | 66  | 12                       | 200  | 4                        | 66   | 8650                                              | 88                                                                            | 11 [0.43]                                   | 19 [0.75]                                          | 5.43<br>[1220]                          | 4.1 [0.16]                                    |
| SAE 8630              | Normalized<br>& drawn | 1.59<br>[0.062]            | 16 [0.63]                     | 7.9 [0.31]                    | 150<br>[6.0]                | 80.17 [1800]                                            | 10                     | 166 | 36                       | 600  | 10                       | 166  | 12 800                                            | 83                                                                            | 16 [0.63]                                   | 38 [1.50]                                          | 18.86<br>[4240]                         | 6.9 [0.27]                                    |
| SAE 8630              | Normalized<br>& drawn | 3.18<br>[0.125]            | 25 [1.00]                     | 15.9<br>[0.63]                | 254<br>[10.0]               | 20.02 [4500]                                            | 45                     | 750 | 210                      | 3500 | 90                       | 1500 | 21 800                                            | 84                                                                            | 22 [0.87]                                   | 64 [2.52]                                          | 58.72 [13<br>200]                       | 14.0 [0.55]                                   |
| SAE 8715              | Normalized<br>& drawn | 0.46<br>[0.018]            | 13 [0.50]                     | 3.2 [0.13]                    | 150<br>[6.0]                | 1.56 [3500]                                             | 3                      | 50  | 4                        | 66   | 3                        | 50   | 3900                                              | 85                                                                            | 11 [0.43]                                   | 16 [0.63]                                          | 1.78 [400]                              | 2.5 [0.10]                                    |
| SAE 8715              | Normalized<br>& drawn | 1.59<br>[0.062]            | 16 [0.63]                     | 7.9 [0.31]                    | 150<br>[6.0]                | 7.12 [1600]                                             | 10                     | 166 | 28                       | 466  | 10                       | 166  | 12 250                                            | 85                                                                            | 16 [0.63]                                   | 38 [1.50]                                          | 14.68<br>[3300]                         | 6.9 [0.27]                                    |
| SAE 8715              | Normalized<br>& drawn | 3.18<br>[0.125]            | 25 [1.00]                     | 15.9<br>[0.63]                | 254<br>[10.0]               | 20.02 [4500]                                            | 45                     | 750 | 180                      | 3000 | 90                       | 1500 | 22 700                                            | 85                                                                            | 22 [0.87]                                   | 64 [2.52]                                          | 56.76 [12<br>760]                       | 14.0 [0.55]                                   |

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

<sup>a</sup> Data obtained from steel companies.

<sup>b</sup> Cycle times shown apply to AC 60 Hz equipment. For 50 Hz equipment, multiply the weld times shown in cycles by 0.83, then round down to the nearest whole number.

<sup>c</sup> Material should be pickled or otherwise cleaned to obtain a surface contact resistance not exceeding 200  $\mu\Omega$ .

<sup>d</sup> Electrode Material: RWMA Class 1, 2, and 20.

<sup>e</sup> Electrode diameter and shape are the same for both upper and lower electrodes.

<sup>f</sup> Electrode diameters are based on the following: ISO Standards 10, 13, 16, 19, and 25 mm; RWMA Standards 0.38, 0.48 (0.50), 0.63, 0.75, 0.88, and 1.00 in.

<sup>g</sup> For DC welding equipment, lower current settings may be appropriate.

<sup>h</sup> Minimum spacing is that spacing for which no special precautions need be taken to compensate for shunted current effect of adjacent welds.

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

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

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

**Table 7**  
**Electrode Materials for Resistance Welding**

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

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

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

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

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

## 4.2 Coated Carbon and Low-Alloy Steels

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

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

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

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

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

(2) Aluminum–Base

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

(3) Lead–tin alloy (Terne coating)

(4) Tin

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

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

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

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

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

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

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

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

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

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

#### **4.2.4.1 Electrodes** (See Table 7)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

## 4.3 Aluminum Alloys

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

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

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

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

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

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

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

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

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

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

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

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

**Table 8**  
**Basic Aluminum Alloy Groups**

| Major Alloying Elements | Designation <sup>a</sup> |
|-------------------------|--------------------------|
| 99.0% Min. Aluminum     | 1xxx                     |
| Copper                  | 2xxx <sup>b</sup>        |
| Manganese               | 3xxx                     |
| Silicon                 | 4xxx                     |
| Magnesium               | 5xxx                     |
| Magnesium and Silicon   | 6xxx <sup>b</sup>        |
| Zinc                    | 7xxx <sup>b</sup>        |

<sup>a</sup> Aluminum association designations.

<sup>b</sup> Heat-treatable alloys.

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

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

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

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

Notes:

**A. Ease of welding**

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

**B. Precleaning**

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

**C. Resistance to corrosion**

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

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

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

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

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

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

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

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

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

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

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

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

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

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

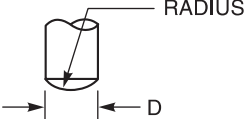
Aluminum has higher shrinkage upon solidification than steel. Use of a low-inertia, low-friction welding head assures rapid follow up to reduce weld defects. In seam welding, higher quality welds are produced with indexing electrode wheels rather than with wheels turning during welding.

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

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

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

**Table 11**  
**Spot-Welding Parameters for Aluminum Alloys on Standard Single-Phase**  
**A-C Type Equipment<sup>a, b, c</sup>**

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

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

<sup>a</sup> Types of aluminum alloy: 1100-H12-H18, 3003-H12-H18, 3004-H32-H38, 5052-H32-H38, 5050-H32-H38, 5356-H32-H38, 6061-T4-T6, 6063-T5-T6.

<sup>b</sup> Cycle times shown apply to AC 60 Hz equipment. For 50 Hz equipment, multiply the weld times shown in cycles by 0.83, then round down to the nearest whole number.

<sup>c</sup> For DC welding equipment, lower current settings may be appropriate.

<sup>d</sup> Electrode material: RWMA Class 1.

<sup>e</sup> Electrode diameters are based on the following: ISO Standards 13, 16, 19, and 22 mm; RWMA Standards 0.48 (0.50), 0.63, 0.75, 0.88, and 1.00 in.

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

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

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

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

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

**Table 12**  
**Spot-Welding Parameters for Aluminum Alloys on Single-Phase A-C Slope Control Type Machines<sup>a</sup>**

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

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

<sup>a</sup> For DC welding equipment, lower current settings may be appropriate.

<sup>b</sup> Electrode material RWMA Class 1.

<sup>c</sup> Electrode diameters are based on the following: ISO Standards 13, 16, 19, and 25 mm; RWMA Standards 0.48(0.50), 0.63, 0.75, 0.88, and 1.00 in.

<sup>d</sup> The top and bottom electrodes should have the same tip radius, or one has a radius tip and the other a flat tip.

<sup>e</sup> Cycle times shown apply to AC 60 Hz equipment. For 50 Hz equipment, multiply the weld times shown in cycles by 0.83, then round down to the nearest whole number.

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

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

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

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

**Table 13**  
**Spot-Welding Parameters for Aluminum Alloys on Three-Phase Rectifier-Type Equipment<sup>a</sup>**

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

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

<sup>a</sup> For DC welding equipment, lower current settings may be appropriate.

<sup>b</sup> Electrode material: RWMA Class 1.

<sup>c</sup> The top and bottom electrodes should have the same tip radius, or one has a radius tip and the other a flat tip.

<sup>d</sup> Electrode diameters are based on the following: ISO Standards 13, 16, 19, and 25 mm; RWMA Standards 0.48(0.50), 0.63, 0.75, 0.88, and 1.00 in.

<sup>e</sup> The force and current values for alloys are 2014-T3, T4, T6, 2024-T3, T4, and 7075-T6. Somewhat lower values may be used for alloys such as 5052 and 6061.

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

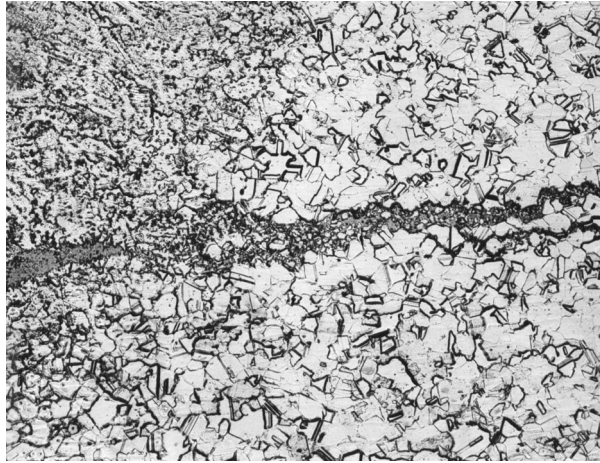


**Figure 1—Coring in Nickel Alloy 718 (UNS N07718) Resistance Seam Weld, 200X**

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

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

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

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

- (1) Plate the faying surfaces with a higher electrical resistance metal (e.g., tin or nickel) to compensate for the low electrical resistance of the base metal. This technique, best described as resistance brazing, can greatly improve the effectiveness of the bond. Since the plating (brazing filler metal) will remain in the joint, its acceptability should be evaluated based on the service requirements.
- (2) Use electrodes faced with a refractory metal like tungsten or molybdenum (e.g., RWMA Group B, Classes 13, and 14), to reduce alloying and sticking of the electrodes to the workpiece.
- (3) Use a short weld time to minimize metal expulsion and sticking of the electrode to the workpiece.
- (4) Because of the narrow plastic range of copper and copper alloys, use machines with a low-inertia welding head. This provides faster follow-up to maintain pressure on the joint to prevent metal expulsion.

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

**Table 14**  
**Spot-Welding Parameters for Aluminum Alloys on Three-Phase Frequency**  
**Converter-Type Equipment (Single Impulse Welds)<sup>a,b</sup>**

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

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

<sup>a</sup> Cycle times shown apply to AC 60 Hz equipment. For 50 Hz equipment, multiply the weld times shown in cycles by 0.83, then round down to the nearest whole number.

<sup>b</sup> For DC welding equipment, lower current settings may be appropriate.

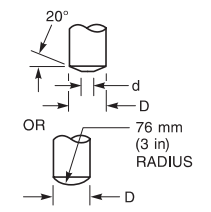
<sup>c</sup> Electrode material: RWMA Class 1.

<sup>d</sup> Electrode diameters are based on the following: ISO Standards 8, 13, 16, 19, and 22 mm; RWMA Standards 0.31, 0.48 (0.50), 0.63, 0.75, 0.88, and 1.00 in.

<sup>e</sup> MIL = military requirements.

<sup>f</sup> COMM = commercial requirements.

**Table 15**  
**Spot-Welding Parameters for Stainless Steels<sup>a</sup>**

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

Note: The parameters shown represent a starting point from which the parameters should be established.

<sup>a</sup> Types of steel 200 and 300 series, all grades.

<sup>b</sup> Electrode material RWMA Class 2 or Class 3.

<sup>c</sup> Electrode diameters are based on the following: ISO Standards 13, 16, 19, and 22 mm; RWMA Standards 0.48 (0.50), 0.63, 0.75, 0.88, and 1.00 in.

<sup>d</sup> Cycle times shown apply to AC 60 Hz equipment. For 50 Hz multiply the weld times shown in cycles by 0.83 and round down to the nearest whole number.

<sup>e</sup> For DC welding equipment, lower current settings may be appropriate.