

ANSI/AWS C5.4-93
An American National Standard

Recommended Practices for Stud Welding



American Welding Society

Keywords — arc stud welding, discharge, ferrule,
stud welding, troubleshooting

ANSI/AWS C5.4-93
An American National Standard

Approved by
American National Standards Institute
June 28, 1993

Recommended Practices for Stud Welding

Superseding AWS C5.4-84

Prepared by
AWS Committee on Arc Welding and Cutting

Under the Direction of
AWS Technical Activities Committee

Approved by
AWS Board of Directors

Abstract

These recommended practices for stud welding, prepared by the Subcommittee on Stud Welding of the AWS Committee on Arc Welding and Cutting, are intended to serve as a basic guide for those interested in attaching fasteners by arc and capacitor discharge stud welding.

The variations of the process, stud design, equipment, welding procedures, quality control, and safety precautions are discussed. The information presented will guide the designer and the shop in the utilization of studs in many fields including automotive manufacture, boiler and building construction, farm and industrial equipment, railroads and shipbuilding, aircraft and aerospace, metal furniture, and other metal working industries.



American Welding Society

550 N.W. LeJeune Road, P.O. Box 351040, Miami, Florida 33135

Statement on Use of AWS Standards

All standards (codes, specifications, recommended practices, methods, classifications, and guides) of the American Welding Society are voluntary consensus standards that have been developed in accordance with the rules of the American National Standards Institute. When AWS 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.

International Standard Book Number: 0-87171-418-3

American Welding Society, 550 N.W. LeJeune Road, P.O. Box 351040, Miami, Florida 33135

© 1993 by American Welding Society. All rights reserved
Printed in the United States of America

Note: The primary purpose of AWS is to serve and benefit its members. To this end, AWS provides a forum for the exchange, consideration, and discussion of ideas and proposals that are relevant to the welding industry and the consensus of which forms the basis for these standards. By providing such a forum, AWS does not assume any duties to which a user of these standards may be required to adhere. By publishing this standard, the American Welding Society does not insure anyone using the information it contains against any liability arising from that use. Publication of a standard by the American Welding Society does not carry with it any right to make, use, or sell any patented items. Users of the information in this standard should make an independent, substantiating investigation of the validity of that information for their particular use and the patent status of any item referred to herein.

With regard to technical inquiries made concerning AWS standards, oral opinions on AWS standards may be rendered. However, 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 Filler Metal Committee. It must be reviewed every five years. This standard is subject to revision at any time by the AWS Committee on Arc Welding and Cutting. It must be reviewed every five years and if not revised, it must be either reapproved 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 Committee on Arc Welding and Cutting 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 Committee on Arc Welding and Cutting 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, 550 N.W. LeJeune Road, P.O. Box 351040, Miami, Florida 33135.

Personnel

AWS Committee on Arc Welding and Cutting

<i>B. L. Shultz, Chairman</i>	The Taylor-Winfield Corporation
<i>L. R. Soisson, 1st Vice Chairman</i>	Welding Consultants
<i>N. E. Larson, 2nd Vice Chairman</i>	Praxair, Incorporated
<i>W. A. Dierschow, Secretary</i>	American Welding Society
<i>D. R. Amos</i>	Westinghouse Turbine Plant
<i>J. W. Barton</i>	Hypertherm, Incorporated
<i>E. R. Bohnart*</i>	Miller Electric Manufacturing Company
<i>H. A. Chambers</i>	TRW Nelson Stud Welding Division
<i>C. Connelly</i>	Applied Fusion Technology, Incorporated
<i>D. A. Fink</i>	The Lincoln Electric Company
<i>J. R. Hannahs</i>	PMI Food Equipment Group
<i>R. T. Hemzacek*</i>	Consultant
<i>G. K. Hicken</i>	Sandia National Laboratory
<i>J. E. Hinkel</i>	The Lincoln Electric Company
<i>D. B. Holliday</i>	Westinghouse Electric Corporation
<i>D. W. Meyer</i>	The ESAB Group
<i>E. R. Pierre</i>	Liquid Air Corporation

AWS Subcommittee on Stud Welding

<i>H. A. Chambers, Chairman</i>	TRW Nelson Stud Welding Division
<i>W. A. Dierschow, Secretary</i>	American Welding Society
<i>R. L. Alley</i>	American Welding Society
<i>J. Colella</i>	L-Tec Welding and Cutting Systems
<i>B. W. Folkening</i>	FMC Corporation
<i>J. C. Jenkins</i>	Consultant
<i>D. E. Kuehn</i>	TRW Nelson Stud Welding Division
<i>R. W. McClellan</i>	Ingalls Shipbuilding
<i>C. C. Pease</i>	C. P. Metallurgical
<i>B. L. Shultz*</i>	The Taylor-Winfield Corporation

* Advisor

Foreword

(This Foreword is not a part of ANSI/AWS C5.4-93, *Recommended Practices for Stud Welding*, but is included for information purposes only.)

These recommended practices for stud welding are intended to serve as a basic guide for those interested in attaching fasteners by arc stud welding, including capacitor discharge methods.

Arc stud welding is an alternative method to other welding processes, as well as drilling and tapping through bolting, etc., and provides a one-sided method of attachment. The present document further expands the document published in 1984.

Comments and suggestions for the improvement of this standard are welcome. They should be sent to the Managing Director, Technical Services Division, American Welding Society, 550 N.W. LeJeune Road, P.O. Box 351040, Miami, Florida 33135.

Official interpretations of any of the technical requirements of this standard may be obtained by sending a request, in writing, to the Managing Director, Technical Services Division, American Welding Society. A formal reply will be issued after it has been reviewed by the appropriate personnel following established procedures.

Table of Contents

	Page No.
<i>Personnel</i>	iii
<i>Foreword</i>	iv
<i>List of Tables</i>	vii
<i>List of Figures</i>	viii
 <i>1. Process Description</i>	 1
1.1 Arc Stud Welding	1
1.2 Capacitor Discharge Stud Welding	3
 <i>2. Selection of Method</i>	 4
2.1 Fastener Size	5
2.2 Base Metal Thickness	5
2.3 Base Metal Composition	5
2.4 Capacitor Discharge (CD) Method	5
 <i>3. Designing for Stud Welding</i>	 6
3.1 Base Metal	6
3.2 Stud Design Ratio	7
 <i>4. Considerations for Stud Selection</i>	 7
4.1 Arc Stud Welding	7
4.2 Capacitor Discharge Studs	11
4.3 Stud Tensile and Torque Strengths	12
 <i>5. Equipment for Stud Welding</i>	 12
5.1 Arc Stud Welding Equipment	12
5.2 Capacitor Discharge Stud Welding Equipment	17
5.3 Automatic Feed Systems	17
 <i>6. Stud Welding Low Carbon and Austenitic Stainless Steels</i>	 17
6.1 Base Metal Preparation	17
6.2 Welding Requirements	18
6.3 Welding Technique for Steels	18
 <i>7. Stud Welding Aluminum Alloys</i>	 20
7.1 Base Metal Preparation	20
7.2 Shielding Gas	20
7.3 Welding Requirements	20
7.4 Welding Technique for Aluminum	20
 <i>8. Stud Locating Techniques</i>	 23
8.1 Locating with Templates	23
8.2 Locating with Spacers	23
8.3 Fixed Guns	24
8.4 Methods of Ensuring Perpendicularity	24
8.5 Special Accessories	28
 <i>9. Quality Control and Inspection</i>	 28
9.1 Steel Studs	28
9.2 Aluminum Studs	30

	Page No.
10. Weld Troubleshooting	31
10.1 Cold Welds	31
10.2 Hot Welds	31
10.3 Stud Hang-Up	31
11. Safety Precautions	32
11.1 General	32
11.2 Electrical	32
11.3 Fire Protection	32
11.4 Vision Protection	32
11.5 Hearing Protection	32
11.6 Protective Clothing	32
11.7 Ventilation	33
11.8 Other	33
11.9 Maintenance	33
11.10 References	33
Annex — Commonly Used Metric Conversions	35
Document List	(Inside Back Cover)

List of Tables

Table		Page No.
1	Stud Welding Method Selection Chart	5
2	Typical Combinations of Base and Stud Metals for Stud Welding	6
3	Recommended Minimum Base Metal Thickness of Steel and Aluminum for Arc Stud Welding	8
4	Typical Length Reductions of Studs in Arc Stud Welding	9
5	Weld Flash Clearance for Arc Welded Full Base Studs	12
6	Standard Arc Welding Studs — Tensile/Torque Strengths	14
7	Approximate Tensile and Torque Strengths of Capacitor Discharge Welded Studs	15
8	Typical Stud Welding Conditions for Joining Low Carbon and Stainless Steel Studs to Similar Base Metals	19
9	Comparable Rectangular and Round Studs	21
10	Typical Welding Conditions for Arc Stud Welding of Aluminum Alloys	23
11	Minimum Required Torque Values and Tension Loads for Arc Stud Welding	31

List of Figures

Figure	Page No.
1A Equipment Setup for Arc Stud Welding of Steel	2
1B Power-Control Type Power Source Setup for Arc Stud Welding of Steel	2
2 Steps in Arc Stud Welding	3
3 Steps in Contact Capacitor Discharge Stud Welding	4
4 Steps in Gap Capacitor Discharge Stud Welding	4
5 Steps in Drawn-Arc Capacitor Discharge Stud Welding	4
6 Commonly Used Studs and Fastening Devices for Arc Stud Welding	8
7 Typical Stud Welds with Shrink Fissures in the Upper Portion of the Weld Flash	10
8 Stud Flash May be Accommodated by Use of Oversized Clearance Holes, Use of Gasket Material, and Use of a Dog or Hold-Down Clip	12
9 Commonly Used Studs for Capacitor Discharge Stud Welding	13
10 Oscillograph Traces of Current and Voltages in Arc Stud Welding	15
11 Arc Stud Welding Capacity for DC Power Sources	16
12 Effect of Cable Size and Length on Available Welding Current from a 2000A Power Source	17
13 Portable Arc Stud Welding Equipment	18
14 Recommended Orientation for Welding Rectangular Studs to a Vertical Surface	19
15 Satisfactory and Unsatisfactory Arc Stud Welds	20
16 Arc Stud Weld with Proper Flash Indicative of a Good Weld	21
17 Examples of Satisfactory and Unsatisfactory Capacitor Discharge Stud Welds	22
18 Equipment Setup for Arc Stud Welding of Aluminum	22
19 Simple Template Used to Locate Studs Within $\pm 1/32$ in. (0.8 mm)	24
20 Simple Template for Capacitor Discharge Welds	24
21 Template with Hardened and Ground Bushing and Welding Gun Adaptor	24
22 Locating with Spacer	25
23 Locating from Adjacent Studs	25
24 Locating from Nearby Surface and Previous Stud	25
25 Mounting Gun in a Fixed Position	25
26 Bipod Foot Plate Assembly for 1/2 in. (12.7 mm) Diameter and Smaller Studs	25
27 Bipod Foot for 1/2 in. (12.7 mm) Diameter and Larger Shear Connector Studs	25
28 Bipods for Unusual Surface Contours	26
29 Typical Ferrule Tube Extension Application	27
30 Typical Offset Assembly	27
31 Ferrule Foot Plate	27
32 Typical Extension Assembly	28
33 Stud Hang-Up	28
34 Cold Weld	29
35 Hot Weld	29
36 Bend Test for Welded Studs to Determine Acceptable Welding Procedures	30
37 Method of Applying a Tensile Load to a Welded Stud Using Torque — a Bolt Can Be Used for an Internal Thread	30

Recommended Practices for Stud Welding

1. Process Description

Stud welding is a general term for joining a metal stud or similar part to a workpiece.¹ Welding can be done by a number of welding processes including arc, resistance, friction, and percussion. The arc stud welding process (SW), including capacitor discharge methods, will be covered in this document.

In arc stud welding, the base (end) of the stud is joined to the other work part by heating them with an arc drawn between the two. When the surfaces to be joined are properly heated, they are brought together under pressure. Stud welding guns are used to hold the studs and move them in proper sequence during welding. There are two basic power supplies used to create the arc for welding studs. One type uses dc power sources similar to those used for shielded metal arc welding. The other type uses a capacitor storage bank to supply the arc power.

The arc stud welding processes using these power sources are commonly known as *arc stud welding* and *capacitor discharge stud welding* respectively.

1.1 Arc Stud Welding. The arc stud welding process involves the same basic principles as any other arc welding process. Application of the process consists of two steps:

(1) Welding heat is developed with an arc between the stud and the plate (work).

(2) The two pieces are brought into intimate contact when the proper temperature is reached.

The equipment consists of the stud gun, a control unit (timing device), studs and ferrules, and an available

source of dc welding current. Typical arc stud welding equipment connections are shown in Figures 1A and 1B. The mechanics of the process are illustrated in Figure 2. The stud is loaded into the chuck, the ferrule (also known as an *arc shield*) is placed in position over the end of the stud, and the gun is properly positioned for welding, Figure 2(A). The trigger is then depressed, starting the automatic welding cycle.

A solenoid coil within the body of the gun is energized. This lifts the stud off the work and, at the same time, creates an arc, Figure 2(B). The end of the stud and part of the workpiece are melted by the arc. When the preset arc period is completed, the welding current is automatically shut off and the solenoid de-energized by the control unit. The mainspring of the gun plunges the stud into the molten pool on the work to complete the weld, Figure 2(C). The gun is then lifted from the stud and the ferrule is broken off, Figure 2(D).

The time required to complete a weld varies with the cross-sectional area of the stud. For example, weld time typically would be about 0.13 seconds for a 10 gage (0.134 in. [2.6 mm]) stud, and 0.92 seconds for a 7/8 in. (22 mm) diameter stud. Application rates vary with the size of the stud and other factors such as working conditions. An average rate is approximately six studs per minute, although a rate of fifteen studs per minute is common in many applications.

The equipment involved in stud welding compares with that of manual shielded metal arc welding with regard to portability and ease of operation. The initial cost of such equipment varies with the size of the studs to be welded.

The gun and the control unit are connected to a dc power source. The control unit connections shown in Figure 1 are for power sources designed for secondary interruption, as is the case with motor-generator sets, battery units, and

1. Stud welding is also discussed in the *Welding Handbook*, Vol. 2, 8th Ed., American Welding Society, 1991.

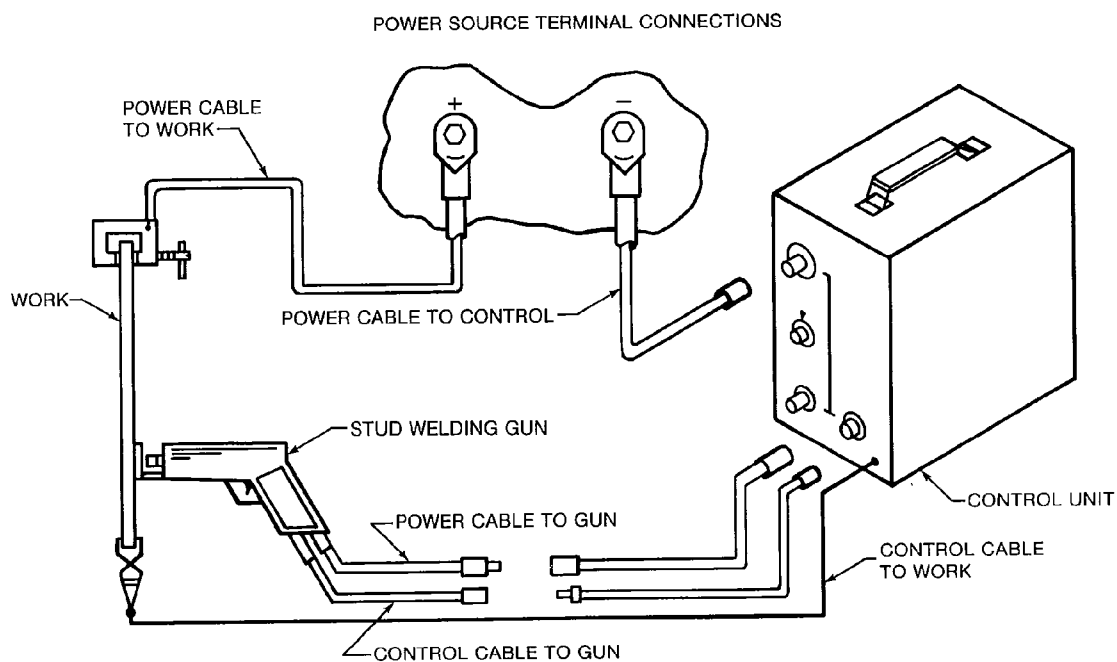


Figure 1A — Equipment Setup for Arc Stud Welding of Steel

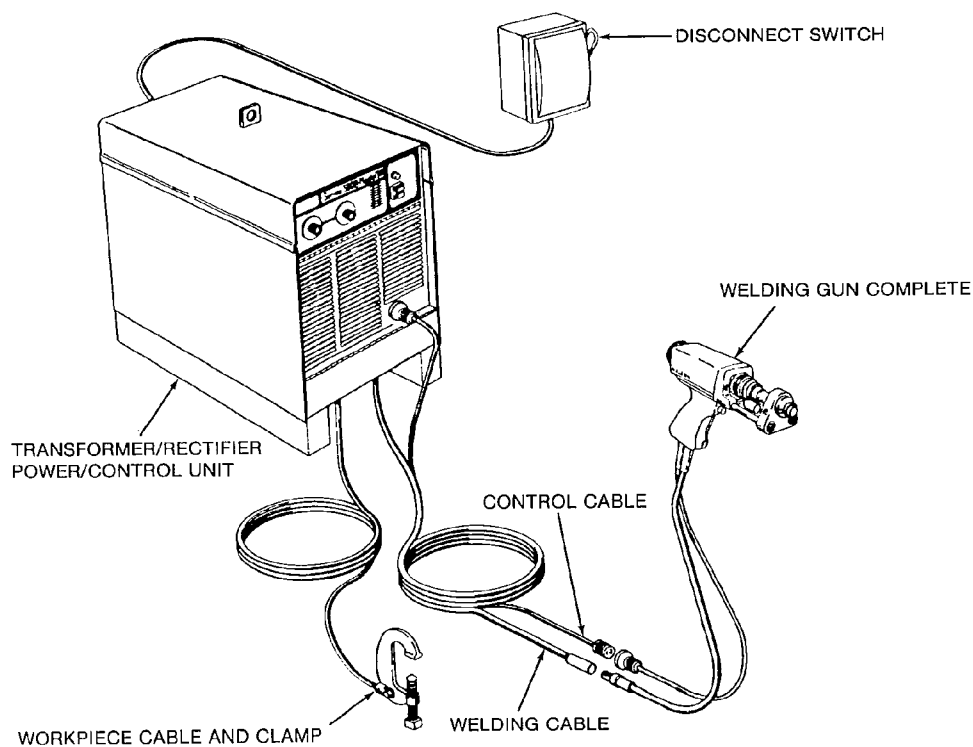
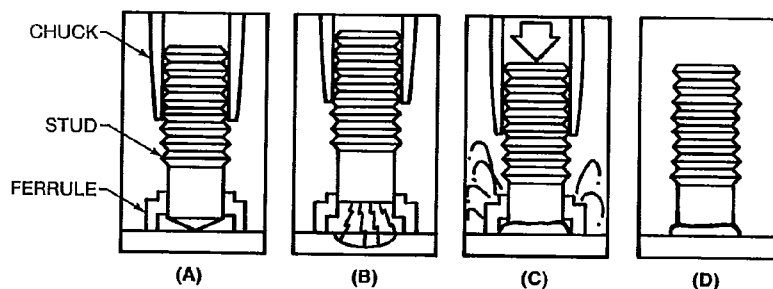


Figure 1B — Power-Control Type Power Source Setup for Arc Stud Welding of Steel



- (A) Gun is properly positioned.
 (B) Trigger is depressed and stud is lifted, creating an arc.
 (C) Arcing period is completed, and stud is plunged into the molten pool of metal on the base metal.
 (D) Gun is withdrawn from the welded stud, and ferrule is removed.

Figure 2 — Steps in Arc Welding

most rectifier-type welding machines. Figure 1A shows connection for an integrated power-control-type power source.

Arc stud welding is used to best advantage when the base metal is heavy enough to support the full strength of the welded stud, but it is often used with lighter gage metals.

1.2 Capacitor Discharge Stud Welding. Capacitor discharge methods of the arc stud welding process use dc power produced by a rapid discharge of stored electrical energy with pressure applied during or immediately following the electrical discharge. The method uses an electrostatic storage system as a power source in which the weld energy is stored in capacitors of high capacitance. No ferrule or fluxing is required. There are two basic pieces of equipment with associated cables: (1) the control-power unit, and (2) the stud gun.

There are three types of capacitor discharge stud welding: contact, gap, and drawn-arc. They differ primarily in the manner of arc initiation. Initial contact and initial gap capacitor discharge stud welding utilize studs having a small, specially designed projection (tip) on the weld end of the stud. Drawn-arc capacitor discharge stud welding creates a pilot arc as the stud is lifted off the workpiece by the stud gun. It is similar to arc stud welding.

1.2.1 Contact Method. With the contact method, the stud is first placed against the work as shown in Figure 3(A). The stored energy is then discharged through a projection on the base of the stud. The small projection presents a high resistance to the stored energy, and it rapidly disintegrates from the high current density. This creates an arc that melts the two surfaces to be joined, Figure 3(B). During arcing, Figure 3(C), the pieces to be joined are being brought together by action of a spring, weight, or an air cylinder. When the two surfaces come in contact, fusion takes place, and a weld is produced between the stud and the workpiece, Figure 3(D).

1.2.2 Gap Method. The sequence of events in the gap method is shown in Figure 4. Initially, the stud is positioned off the work, leaving a gap between it and the work, as shown in Figure 4(A). The stud is released and continuously moves toward the work under gravity, air pressure, or spring loading. At the same time, open-circuit voltage is applied between the stud and the work. When the stud contacts the work, Figure 4(B), high current flashes off the tip and initiates an arc. The arc melts the surface of the stud and work as the stud continues to move forward, Figure 4(C). Finally, the stud plunges into the work, and the weld is completed, Figure 4(D).

With proper design of the electrical characteristics of the circuit and size of the projection, it is possible to produce a high current arc of such short duration, about 6 milliseconds (ms), that its effect upon the stud and workpiece is purely superficial. A surface layer only a few thousandths of an inch in thickness on each surface reaches the molten state yet produces a strong welding joint.

1.2.3 Drawn-Arc Method. In the drawn-arc capacitor discharge method, arc initiation is accomplished in a manner similar to that of arc stud welding. The stud does not require a small tip on the weld face. An electronic control is used to sequence the operation. Weld time is controlled by an electronic circuit in the unit. The welding gun is similar to that used for arc stud welding. The operation is shown in Figure 5. In sequence, the stud is positioned against the work as shown in Figure 5(A). The trigger switch on the stud welding gun is actuated, energizing the welding circuit and a solenoid coil in the gun body. The coil motion lifts the stud from the work, Figure 5(B), drawing a low-amperage pilot arc between them. When the lifting coil is de-energized, the stud starts to return to the work. The welding capacitors are then discharged across the arc. The high amperage from the capacitors melts the end of the stud and the adjacent work

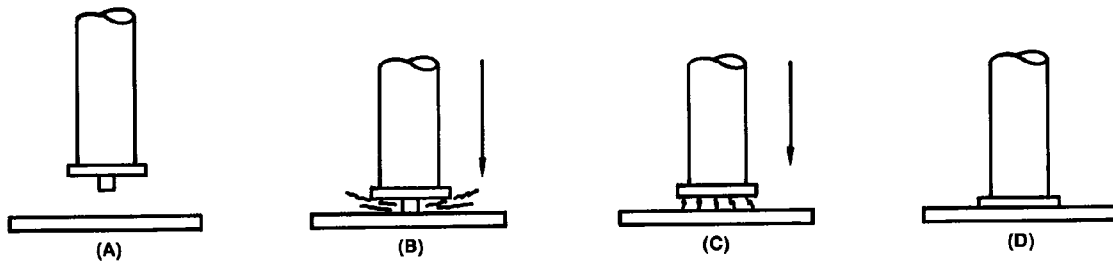


Figure 3 — Steps in Contact Capacitor Discharge Stud Welding

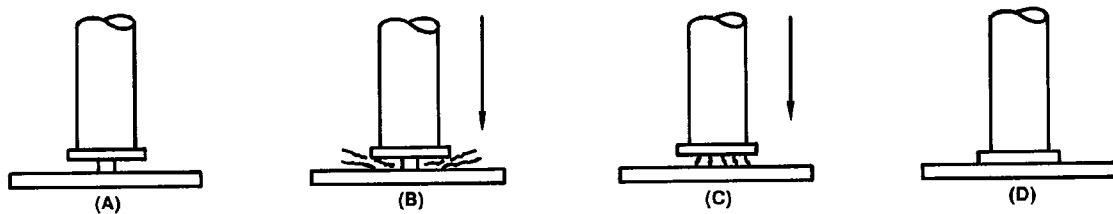


Figure 4 — Steps in Gap Capacitor Discharge Stud Welding

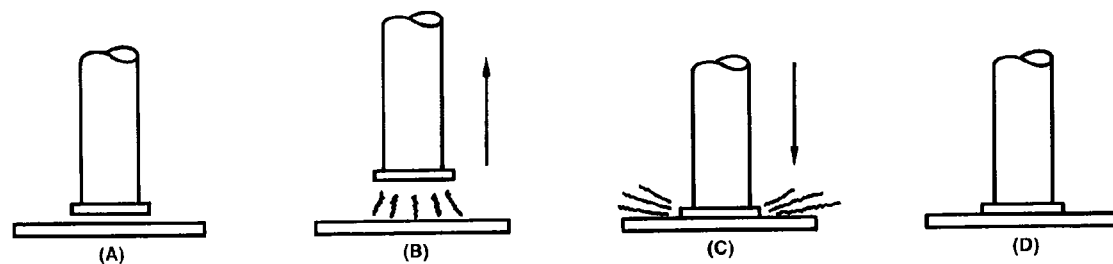


Figure 5 — Steps in Drawn-Arc Capacitor Discharge Stud Welding

surface. The spring action of the welding gun plunges the stud into the molten metal to complete the weld, Figure 5(C). The completed weld is shown in Figure 5(D).

A short welding time, 3 to 6 milliseconds (ms) for the gap and contact methods and 6 to 12 ms for the drawn-arc method, prevents heat buildup in the workpiece. This permits welding of studs to thin metal sections without discoloration or melt-through. Depending upon the section thickness, a paint or vinyl coating on the other side of the welded surface is not damaged. The shallow penetration permits many dissimilar metals to be welded with acceptable strengths and metallurgical characteristics.

2. Selection of Method

There are some applications for which the capabilities of arc stud welding and capacitor discharge stud welding overlap, but generally the selection between these two basic methods is well defined. A selection chart is shown in Table 1. The area in which selection is usually more difficult is the choice of the capacitor discharge method to use, i.e., contact, gap, or drawn-arc.

The main criteria for selecting the stud welding method are fastener size, base metal thickness, and base metal composition. Using these criteria, it is almost always possible to select the best method.

Table 1
Stud Welding Method Selection Chart

Factors to be Considered	Arc Stud Welding	Capacitor Discharge Stud Welding	
		Gap and Contact	Drawn- Arc
Stud shape	A	A	A
Round	A	A	A
Square	A	A	A
Rectangular	A	A	A
Irregular	A	A	A
Stud diameter or area			
1/16 to 1/8 in. (1.6 to 3.2 mm)	D	A	A
1/8 to 1/4 in. (3.2 to 6.4 mm)	C	A	A
1/4 to 1/2 in. (6.4 to 12.7 mm)	A	B	B
1/2 to 1 in. (12.7 to 25.4 mm)	A	D	D
Up to 0.05 in. ² (32.3 mm ²)	C	A	A
Over 0.05 in. ² (32.3 mm ²)	A	D	D
Stud metal			
Carbon steel	A	A	A
Stainless steel	A	A	A
Alloy steel	B	C	C
Aluminum	B	A	A
Brass	C	A	D
Base metal			
Carbon steel	A	A	A
Stainless steel	A	A	A
Alloy steel	B	A	C
Aluminum	B	A	A
Brass	C	A	D
Base metal thickness			
Under 0.015 in. (0.4 mm)	D	A	B
0.015 to 0.062 in. (0.4 mm to 1.6 mm)	C	A	A
0.062 to 0.125 in. (1.6 mm to 3.2 mm)	B	A	A
Over 0.125 in. (3.2 mm)	A	A	A
Strength criteria			
Heat effect on exposed surfaces	B	A	A
Weld fillet clearance	B	A	A
Strength of stud governs	A	A	A
Strength of base metal governs	A	A	A

Legend:

- A — Applicable without special procedures or equipment.
 B — Applicable with special techniques or for specific applications that justify preliminary trials or testing to develop welding procedure and technique.
 C — Limited application.
 D — Not recommended. Welding methods not developed at this time.

2.1 Fastener Size. For studs over 5/16 in. (7.9 mm) diameter, the arc stud welding method must be used for portable applications. The capacitor discharge stud welding methods are limited to 5/16 in. (7.9 mm) diameter with hand-held guns and to 3/8 in. (9.5 mm) diameter studs with fixed or production-type equipment. Applications suitable for capacitor discharge welding with studs in the 5/16 to 3/8 in. (7.9 to 9.5 mm) diameter range generally involve thin base materials where avoidance of reverse side marking or heat transfer is the foremost requirement, i.e., stainless steel kitchen counters or full gasoline storage tanks.

2.2 Base Metal Thickness. For base thicknesses under 0.062 in. (1.6 mm), the capacitor discharge stud welding methods should be used. Using these methods, the base metal can be as thin as 0.020 in. (0.5 mm) without melt-through occurring. On such thin material, the sheet will tear when the stud is loaded excessively. Reverse side marking is the principal effect involved in appearance.

Using the arc stud welding process, the base metal thickness should be at least one-third the weld base diameter of the stud to assure maximum stud strength. Where strength is not the foremost requirement, the base metal thickness may be a minimum of one-fifth the weld base diameter.

2.3 Base Metal Composition. For mild steel, austenitic stainless steel (except Type 303, and various aluminum alloys), arc stud welding, or any of the capacitor discharge methods can be used. For copper, brass, and galvanized steel sheet, the capacitor discharge process is best suited.

2.4 Capacitor Discharge (CD) Methods. Using the above criteria, if capacitor discharge welding is best suited for the application, then the three alternative capacitor discharge methods must be evaluated. Since there is considerable overlap in the stud welding capabilities of the three methods, there are many applications where any one of them can be used. On the other hand, there are many instances where one method is best suited for the application. Setting up specific guidelines for selection of the best capacitor discharge method is rather difficult. However, usage of the three different methods is generally as follows:

2.4.1 Initial Contact Method. This method, with portable equipment, is used principally for welding mild steel, stainless steel and aluminum studs. Equipment simplicity makes it ideal for welding mild steel insulation pins to galvanized duct work.

2.4.2 Gap Method. This method is used with portable and fixed equipment for welding mild steel, stainless steel, and aluminum and is ideally suited for high-speed production and close-tolerance production. The heads can be automatically fed and parts positioned with computer

numerically controlled equipment. The gap method is generally superior to both the contact and drawn-arc methods for welding dissimilar metals and aluminum. Inert gas shielding is not required for aluminum welding. The gap method produces the least backside marking of all processes and is extremely useful when minimizing backside marking is essential.

2.4.3 Drawn-Arc Method. The types of equipment and materials welded are the same as those of the gap method. The stud does not require a special tip. The method is ideally suited for high-speed-production applications involving automatic feed systems with either portable equipment or fixed-production-type equipment. Inert gas shielding is required for aluminum welding with a drawn-arc.

3. Designing for Stud Welding

3.1 Base Metal. Table 2 shows some typical combinations of base and stud metals for stud welding.

3.1.1 Low-Carbon Steel. Low-carbon (mild) steels can be stud welded with no major metallurgical problems. The upper carbon limit for steel to be arc stud welded without preheat is 0.30 percent. If work sections are relatively thin for the stud diameters being welded, the carbon limit may be somewhat higher because of the

decreased cooling effect of the work. If the section to which the stud is to be welded is relatively thick, stud welding of steel with more than 0.30 percent carbon using normal techniques and without preheat must be evaluated. The most important factor regarding work section thickness is that the material must be heavy enough to permit welding the studs without melt-through.

3.1.2 Medium- and High-Carbon Steel. If medium- and high-carbon steels are to be stud welded, it is imperative that preheat be used to prevent cracking in the heat-affected zones. In some instances, a combination of preheating and postheating after welding is recommended. In the case of tough alloy steels, either preheating or postheating may be used to obtain satisfactory results. In cases where the welded assemblies are to be heat treated for hardening after the welding operation, the preheating or postheating operation may be eliminated if the parts are handled in a manner that prevents damage to the studs.

3.1.3 Low Alloy Steel. Generally, the high-strength, low alloy steels are satisfactorily stud welded when their carbon content is 0.15 percent or lower. This range fits the analyses of low alloy steels used in welding and forming operations. If the carbon content exceeds 0.15 percent, it may be necessary to preheat the work to a low preheat temperature to obtain desired toughness in the weld area.

When the hardness of the heat-affected zones and the stud fillet does not exceed 30 Rockwell C, studs can be

Table 2
Typical Combinations of Base and Stud Metals for Stud Welding

Base Metal	Stud Metal
Arc Stud Welding	
Low-carbon steel, AISI 1006 to 1022 ^b	Low-carbon steel, AISI 1006 to 1020; stainless steel, 300 series
Stainless steel, 300 series ^a , 405, 410, and 430	Low-carbon steel, AISI 1006 to 1020; stainless steel, 300 series
Aluminum alloys, 5000 series ^c	Aluminum alloy 5000 series ^c
Capacitor Discharge Stud Welding	
Low-carbon steel, AISI 1006 to 1022	Low-carbon steel, AISI 1006 to 1020; stainless steel, 300 series; copper alloy 260 and 268
Stainless steel, 300 series and 400	Low-carbon steel, AISI 1006 to 1020; stainless steel, 300 series
Aluminum alloys, 1100, 3000, 5000 series ^c , 6061 and 6063	Aluminum alloy 1100 and 5000 series, and 6061 ^c
ETP copper, lead-free brass, and rolled copper	Low-carbon steel, AISI 1006 to 1022; stainless steel, 300 series; copper alloys C 26000, C26800, and 464
Zinc alloys (die cast)	Aluminum alloys 1100 and 5000 Series ^c

Notes:

a. Except for the free-machining Type 303 stainless steel.

b. Refer to ANSI/AWS D1.1-92, Table 4.1 (Groups I and II) for approved steels.

c. Refer to ANSI/AWS D1.2-89, Tables 7.1 and 7.4.

expected to perform well under almost any type of severe service. Although good results have been obtained with hardness ranges up to 35 Rockwell C, it is best to avoid extremely high working stresses and fatigue loading. In special cases where microstructures are important, the weld should be evaluated and qualified for the specific application considered. Since alloy steels vary in toughness and ductility at high hardness levels, weld hardness should not be used as the sole criterion for weld evaluation.

3.1.4 Heat-Treated Structural Steel. Many structural steels used in shipbuilding and in other construction are heat-treated at the mill. Heat-treated steels require that attention be given to the metallurgical characteristics of the heat-affected zone. Some of these steels are sufficiently hardenable that the heat-affected zones will be martensitic. This structure will be quite sensitive to underbead cracking, and it will have insufficient ductility to carry impact loads. Therefore, for maximum toughness in these steels, a preheat of 700°F (370°C) is recommended. Consideration of the application and end use of the stud will further influence the welding procedures to be followed.

3.1.5 Stainless Steels. Most classes of stainless steel may be stud welded. The exceptions are the free-machining grades. However, only the austenitic stainless steels (300 grades) are recommended for general application. The other types are subject to air hardening, and they tend to be brittle in the weld area unless annealed after welding. The weldable stainless steel grades include American Iron and Steel Institute (AISI) Types 304, 305, 308, 309, 310, 316, 321, and 347. Types 304 and 305 are most commonly used for stud welding.

Stainless steel studs may be welded to stainless steel or to mild steel as the application may require. The welding setup used is the same as that recommended for low-carbon steel except for an increase of approximately 10 percent in power requirement. Where stainless steel studs are to be welded to mild steel, it is essential that the carbon content of the base metal not exceed 0.20 percent. When welding stainless steel studs to mild steel with 0.20 to 0.28 percent carbon, or to low-carbon hardenable steels, Type 308, 309, or 310 studs are recommended. Because of the composition of the weld metal when chromium-nickel alloy studs are welded to mild steel, the weld zone may be quite hard. The hardness will depend on the carbon content in the base metal. It is possible to overcome this by using studs with high-alloy content such as Type 309 or 310. It is also suggested when welding stainless steel studs to mild steel that a fully annealed stainless steel stud be used.

3.1.6 Aluminum. In general, all plate alloys of the 1100, 3000, and 5000 series are considered excellent for stud welding; alloys of the 4000 and 6000 series are

considered fair; and the 2000 and 7000 series are considered poor. Base metal to which studs are to be welded shall be free of anodic coatings, moisture or other injurious material to assure obtaining sound welds. These areas may be cleaned by etching, brushing with a stainless steel bristle brush, scraping or grinding.

3.1.7 Other Materials. On a moderate scale, stud welding is being done commercially on various brass, bronze, nickel-copper, and nickel-chromium-iron alloys. The applications are usually very special ones requiring careful evaluation to determine suitability of design.

Nickel, nickel-copper, nickel-chromium-iron, and nickel-chromium-molybdenum alloys are best stud welded with direct current, electrode positive (DCEP). Nickel, nickel-copper, and nickel-chromium-iron alloy stud welds tend to contain porosity and crevices. The mechanical strengths, however, are usually high enough to meet most requirements. The weld itself should not be exposed to corrosive media.

3.2 Stud Design Ratio

3.2.1 Arc Stud Welding. The base metal thickness should be at least one-third the weld base diameter of the stud. This ratio will assure that the weld is as strong as the stud to utilize the maximum load capacity.

Where strength is not a foremost requirement, the base metal may be as thin as one-fifth the weld base diameter of the welded stud. Table 3 gives the recommended minimum base metal thicknesses for steel and aluminum studs.

3.2.2 Capacitor Discharge Stud Welding. The base metal may be as thin as 0.015 in. (0.4 mm) for steel and 0.025 in. (0.6 mm) for aluminum. Failure will take place in the sheet under tensile load with such thin sections. With thicker sections, the stud should fail under tensile load.

4. Considerations for Stud Selection

4.1 Arc Stud Welding

4.1.1 Studs. Studs are available in various shapes and forms. Standard straight studs, threaded and nonthreaded, have diameters ranging from 1/8 in. (3.2 mm) through 1-1/4 in. (31.8 mm) and lengths as required. It is also possible to obtain female, eyebolt or J-bolt, rectangular, square, punched, slotted, grooved, bent, and pointed studs. Figure 6 shows typical studs for arc stud welding. General requirements for steel shear connectors are given in ANSI/AWS D1.1, *Structural Welding Code — Steel*, latest edition.

Most stud weld bases are round. However, there are many applications that utilize a square or rectangular

Table 3
Recommended Minimum Base Metal Thickness of Steel and Aluminum
for Arc Stud Welding (Where Strength Is not a Criterion)

Stud Base Diameter		Steel without Backup			Aluminum			
					Without Backup		With Backup*	
in.	mm	in.	mm	Manufacturer's Standard Gage	in.	mm	in.	mm
3/16	4.8	0.036	0.91	20	0.125	3.2	0.125	3.2
1/4	6.4	0.048	1.21	18	0.125	3.2	0.125	3.2
5/16	7.9	0.060	1.52	16	0.180	4.7	0.125	3.2
3/8	9.5	0.075	1.90	14	0.180	4.7	0.180	4.7
7/16	11.1	0.090	2.28	13	0.250	6.4	0.180	4.7
1/2	12.7	0.120	3.04	11	0.250	6.4	0.250	6.4
5/8	15.9	0.145	3.8	—	—	—	—	—
3/4	19.1	0.185	4.7	—	—	—	—	—
7/8	22.2	0.250	6.4	—	—	—	—	—
1	25.4	0.375	9.5	—	—	—	—	—

*A metal backup to prevent melt-through of the base metal.

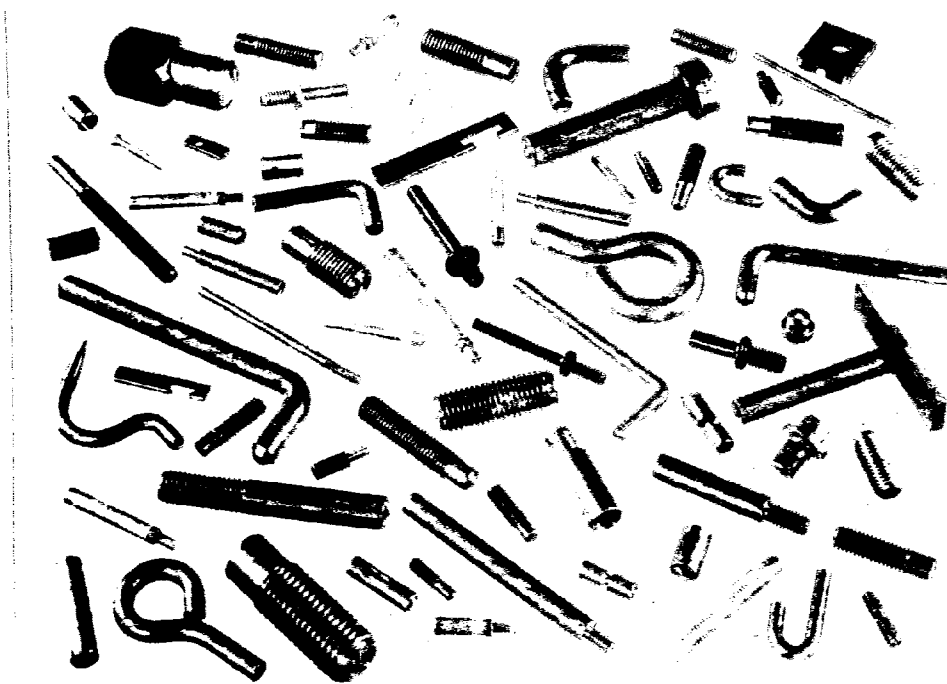


Figure 6 — Commonly Used Studs and Fastening Devices for Arc Stud Welding

shaped stud. With rectangular studs, the width-to-thickness ratio at the weld base should not exceed five to obtain satisfactory welds.

Stud designs are limited in that (1) welds can be made on only one end of a stud; (2) the shape must be such that a ferrule (arc shield) can be produced to fit the weld base; (3) the cross section of the stud weld base must be within the range that can be welded with available equipment; and (4) the stud must have a size and shape that permit chucking or holding for welding. The stud manufacturers can provide information on both standard and special designs for various applications.

A suitable deoxidizing and arc stabilizing flux for welding must be provided in the weld base of each carbon and stainless steel stud of 5/16 in. (8.0 mm) diameter or larger. Studs less than 5/16 in. (8.0 mm) in diameter may be furnished with or without flux, depending upon the design and application.

General purpose studs of any type and size used for purposes other than shear transfer in composite beam design and construction are commonly made of low-carbon steel with a minimum tensile strength of 55 000 psi (380 MPa). Studs (shear connectors) that are used as an essential component in composite beam design and construction are made of low-carbon steel with a minimum tensile strength of 60 000 psi (415 MPa) and a minimum yield strength of 50 000 psi (345 MPa). (These strengths conform to ANSI/AWS D1.1 and ANSI/AASHTO/AWS D1.5, *Bridge Welding Code*.)

One important consideration in designing or selecting a stud is the material lost from the welding action. During welding, the stud and base metal melt. The molten metal is then expelled from the joint. The overall length is reduced by the approximate amounts shown for various stud diameters in Table 4. The stud length reductions shown in the table are typical, but they may vary to some degree depending upon the materials involved. The finished length after welding is shorter than the original stud length by the amount of length reduction.

4.1.2 Ferrules. An individual ferrule (arc shield) is required with each stud for most applications. It is placed over the stud at the weld base where it is held in position by a grip or holder on the stud welding gun. The ferrule performs several important functions during welding:

- (1) Concentrates the heat of the arc in the weld area
- (2) Restricts the flow of air into the weld area, which helps to control oxidation of the molten weld metal
- (3) Confines the molten metal to the weld area
- (4) Prevents the charring of adjacent nonmetallic materials

The ferrule also shields the operator from the arc. However, safety glasses with No. 3 filter lenses are recommended for eye protection.

Table 4
Typical Length Reductions of
Studs in Arc Stud Welding

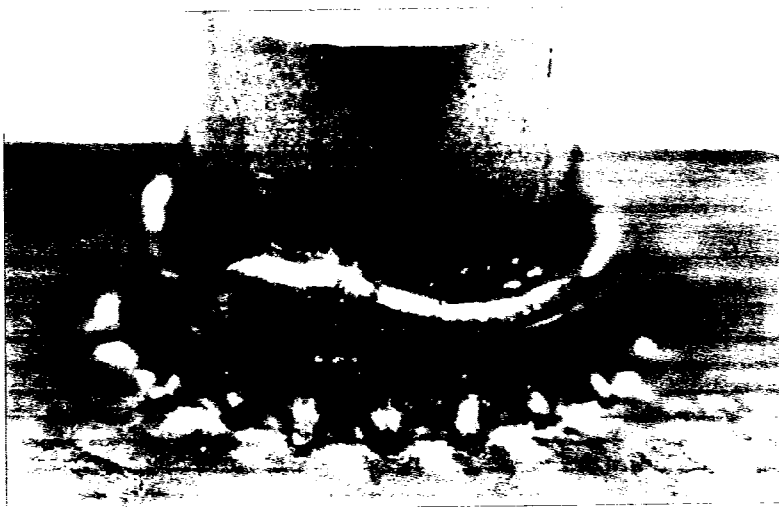
Stud Diameters		Length Reductions	
in.	mm	in.	mm
3/16 through 1/2	4.8 through 12.7	1/8	3.2
5/8 through 7/8	15.9 through 22.2	3/16	4.8
1 and over	25.4 and over	3/16 to 1/4	4.8 to 6.4

Ferrules are made of a ceramic material and are easily removed by breaking them. Since ferrules are designed to be used only once, their size is minimized for economy, and their dimensions are optimized for the application. A standard ferrule is generally cylindrical in shape and flat across the bottom for welding to flat surfaces. The base of the ferrule is serrated to vent gases expelled from the weld area. Its internal shape is designed to form the expelled molten metal into a flash around the base of the stud.² Special ferrule designs are used for special applications such as welding at angles to the work and welding to contoured surfaces. Ferrules for such applications are designed so that their bottom faces match the required surface contours.

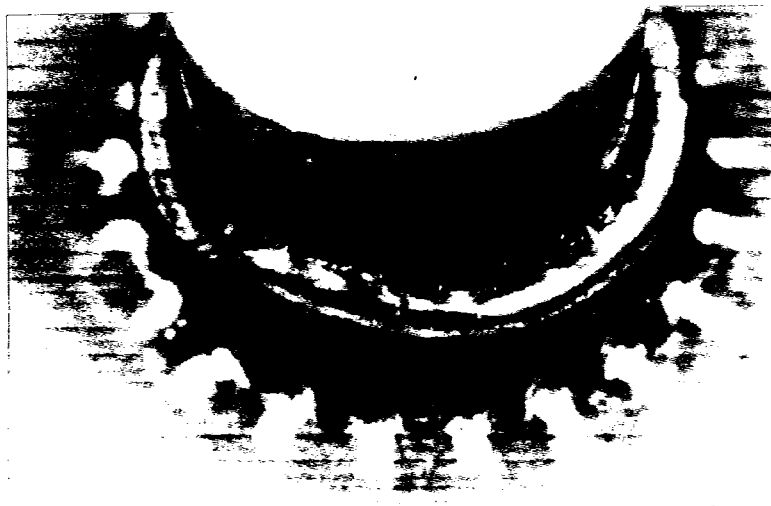
4.1.3 Flash. When a stud is end welded, a flash forms around its base. The contour of the flash can be controlled by the ferrule design when one is used for welding. When properly formed and contained, the flash indicates complete fusion over the full cross section of the stud base. It also suggests that the weld is free of contaminants and porosity.

The expelled metal, which is not required for strength and is not detrimental, is essential to provide a good weld. The containment of this molten metal around the base of a welded stud by the ferrule (arc shield) assists in securing complete fusion over the entire cross section of the weld. The flash may have nonfusion in its vertical leg and overlap on its horizontal leg. It may contain occasional small shrink fissures or discontinuities that usually form on the surface and have essentially radial or longitudinal orientation, or both, to the axis of the stud. Figure 7 shows typical stud welds that have shrink fissures in the upper portion of the weld flash. Nonfusion on the vertical leg of the flash and small shrink fissures are acceptable. The dimensions of the fillet are closely controlled by the design of the ferrule, where one is required.

2. The expelled metal around the base and the stud is called *flash*.



(A)



(B)

**Figure 7 — Typical Stud Welds with Shrink Fissures
in the Upper Portion of the Weld Flash**



(C)

Figure 7 (continued) — Typical Stud Welds with Shrink Fissures in the Upper Portion of the Weld Flash

The diameter of the flash is generally larger than the diameter of the stud; therefore, some consideration is required in the design of mating parts. Counterbore and countersink dimensions that are commonly used to provide flash clearances for various stud sizes are given in Table 5. Flash dimensions will vary with stud material and ferrule clearance. Other methods of accommodating the flash are illustrated in Figure 8.

4.2 Capacitor Discharge Studs

4.2.1 Materials. The stud materials commonly used for capacitor discharge welding are low-carbon steel, stainless steel, aluminum, and brass. Low-carbon steel and stainless steel studs generally have the same compositions as those used for arc stud welding. For aluminum, 1100 and 5000 series studs are generally used. Copper alloy studs are mostly made of C26000 and C26800 alloys.

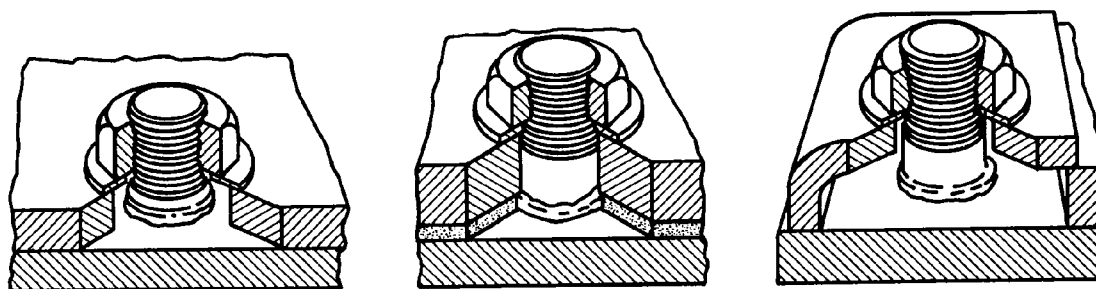
Stud designs for capacitor discharge stud welding range from standard shapes to complex forms for special applications. Usually, the weld base of the fastener is round. The shank may be almost any shape or configuration. These include threaded, plain, round, square, rectangular, tapered, grooved, and bent configurations and flat stampings. The size range is 1/16 to 1/2 in. (1.6 to 12.7 mm) diameter, with the great bulk of attachments falling in the 1/8 to 3/8 in. (3.2 to 9.5 mm) diameter range. Figure 9 shows some common stud designs.

4.2.2 Contact and Gap Stud Design. As stated previously, contact and gap capacitor discharge studs are designed with a tip or projection on the weld end. The size and shape of this tip is important because it is one of the variables involved in the achievement of sound welds. The standard tip is cylindrical in shape. For special applications, a conically shaped tip is used. The detailed weld base design is determined by the stud material, the base diameter, and sometimes by the particular application. The weld face is tapered slightly to facilitate the expulsion of expanding gases that develop during the welding cycle. The weld area is generally larger than the stud cross section but not always, to provide a joint strength equal to or higher than that of the stud. The weld base can be flanged or nonflanged depending on the application and the type of equipment being used. If a flanged stud is used, the weld area would be larger than the stud cross section. The joint strength is enhanced with the flange, but many times a nonflanged stud will develop the full strength of the fastener. The total joint design should be taken into consideration.

4.2.3 Drawn-Arc Stud Design. Drawn-arc capacitor discharge studs are designed without a tip or projection on the weld end. However, the weld end is tapered or slightly spherical so that the arc will initiate at the center of the base. As with the other capacitor discharge methods, these studs are generally designed with a large base in the form of a flange.

Table 5
Weld Flash Clearance for Arc Welded Full Base Studs

Stud Base Diameter		Counterbore				90 deg Countersink Depth	
		Diameter		Depth			
in.	mm	in.	mm	in.	mm	in.	mm
1/4	6.4	0.437	11.1	0.125	3.2	0.125	3.2
5/16	7.9	0.500	12.7	0.125	3.2	0.125	3.2
3/8	9.5	0.593	15.1	0.125	3.2	0.125	3.2
7/16	11.1	0.656	16.7	0.187	4.8	0.125	3.2
1/2	12.7	0.750	19.1	0.187	4.8	0.187	4.8
5/8	15.9	0.875	22.2	0.218	5.5	0.187	4.8
3/4	19.1	1.125	28.6	0.312	7.9	0.187	4.8



(A) USE OF OVERSIZED CLEARANCE HOLES (B) USE OF GASKET MATERIAL (C) USE OF A DOG OR HOLD-DOWN CLIP

Figure 8 — Stud Flash May be Accommodated by: (A), (B), and (C)

Stud melt-off or reduction in length due to melting is almost negligible when compared to the arc stud welding method. Stud melt-off is generally in the range of 0.008 to 0.015 in. (0.2 to 0.4 mm).

4.3 Stud Tensile and Torque Strengths

4.3.1 Tables 6 and 7 give the approximate tensile loads and wrench torques that will produce yielding in various diameters of threaded studs joined by arc and capacitor discharge stud welding, respectively. Table 6 also gives the minimum weld base diameter needed to obtain arc stud welds that will support the tensile and torque loads that will cause yielding. A suitable method for obtaining torque data is described in 9.1.2. Because of the variables affecting the torque-tension relation, these tables should be used only as guides in selecting stud sizes for particular applications. The suitability of a given stud design should be determined by appropriate tests.

4.3.2 It is generally recommended that studs be used at no more than 60 percent of their yield strengths. The user should determine the appropriate safety factor depending on the particular application.

5. Equipment for Stud Welding

5.1 Arc Stud Welding Equipment

5.1.1 Power Sources. A dc type power source is required for arc stud welding. Alternating current is not suitable for stud welding purposes. There are three basic types of power sources that can be used for arc stud welding. They are (1) transformer-rectifier, (2) rotating, and (3) battery. The rotating type may be either an electric motor or engine driven generator.

The general characteristics desired in a stud welding power source are

- (1) High open-circuit voltage in the range of 70 to 100V
- (2) A drooping output volt-ampere characteristic
- (3) A rapid output current rise to the set value
- (4) High current output for a relatively short time

The current requirements are higher, and the duty cycle is much lower for stud welding than for other types of arc welding. Typical current voltage patterns during arc stud welding are shown in Figure 10.

There are standard dc arc welding power sources available which meet these requirements. They are entirely

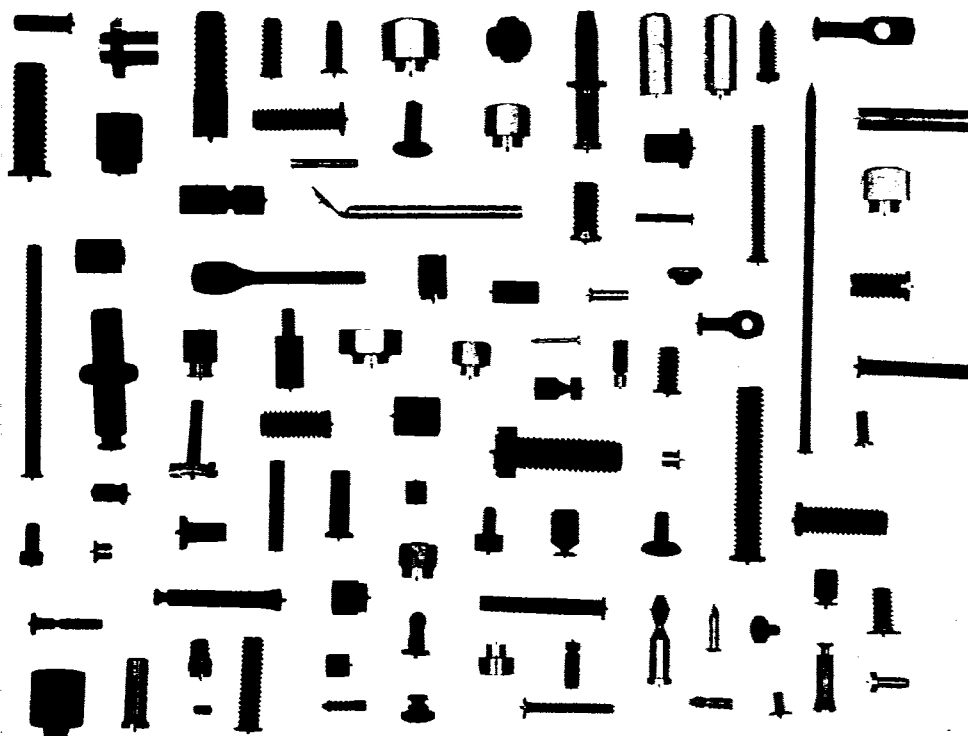


Figure 9 — Commonly Used Studs for Capacitor Discharge Stud Welding

satisfactory for stud welding. Direct current welding power sources with a constant voltage characteristic generally are not suitable for stud welding. With this type power source, weld current control can be difficult, and it may not be possible to obtain the proper weld current range for the application. However, with proper controls, high-output units can be used. Check with the specific manufacturer for details.

Many stud welding current range requirements extend beyond those used for shielded metal arc welding. Therefore, standard dc power sources are generally used only for welding 1/2 in. (12.7 mm) diameter and smaller studs because of the maximum current output limitations. For larger studs, two standard dc type power sources should be used in parallel, or a single unit designed for arc stud welding.

General comments on the use of conventional power sources for stud welding are as follows:

- (1) The power supply must have a minimum open circuit voltage (OCV) of 70V.
- (2) Generally, the smallest National Electrical Manufacturers Association (NEMA) rated power supply suitable for stud welding is a 300A unit, [see (4)].

- (3) Gasoline or diesel engine driven motor generators must be operated at constant RPM. The engine must have a speed governor to operate at a constant speed.

- (4) Paralleling of power sources should only be done in accordance with the manufacturer's recommendations and instructions.

When applications require high welding currents (sometimes over 2500A) and short weld times, special power sources designed specifically for stud welding are recommended.

These special power sources yield higher efficiency not only from the standpoint of weld current output relative to their size and weight but also from the fact that they cost less than two or more standard arc welding machines. Recommended power sources for arc stud welding various ranges of stud sizes are given in Figure 11.

The basis for rating special stud welding power sources is different from that of conventional arc welding machines. Because stud welding requires a high current for a relatively short time (Figure 10), the current output requirements of a stud welding power source are higher, but the duty-cycle is much lower than would be needed for other types of arc welding. Also, the load voltage is normally

Table 6
Standard Arc Welding Studs — Tensile/Torque Strengths

Low-Carbon Steel — 55 000 psi Min. Ultimate, 50 000 psi Min. Yield					
Stud Thread Diameter	META sq. in.	Yield Load (lb) @ 50 000 psi	Ultimate Tensile Load (lb) @ 55 000	Yield Torque* @ 50 000 psi	Ultimate Torque* @ 55 000 psi
10-24 UNC	.017	870	957	33 in. lb	36 in. lb
10-32 UNF	.020	1,000	1,105	37 in. lb	41 in. lb
1/4-20 UNC	.032	1,590	1,743	6 ft lb	7 ft lb
1/4-28 UNF	.036	1,810	1,990	7 ft lb	8 ft lb
5/16-18 UNC	.052	2,620	2,871	13 ft lb	15 ft lb
5/16-24 UNF	.058	2,895	3,184	15 ft lb	17 ft lb
3/8-16 UNC	.078	3,875	4,250	24 ft lb	27 ft lb
3/8-24 UNF	.088	4,380	4,818	27 ft lb	30 ft lb
7/16-14 UNC	.106	5,315	5,830	38 ft lb	42 ft lb
7/16-20 UNF	.118	5,900	6,490	43 ft lb	47 ft lb
1/2-13 UNC	.142	7,095	7,810	59 ft lb	65 ft lb
1/2-20 UNF	.160	8,000	8,800	66 ft lb	73 ft lb
5/8-11 UNC	.226	11,300	12,430	118 ft lb	130 ft lb
5/8-18 UNF	.255	12,750	14,025	133 ft lb	146 ft lb
3/4-10 UNC	.334	16,700	18,370	209 ft lb	230 ft lb
3/4-16 UNF	.372	18,600	20,460	232 ft lb	256 ft lb
7/8-9 UNC	.462	23,100	25,355	337 ft lb	370 ft lb
7/8-14 UNF	.509	23,450	27,995	371 ft lb	408 ft lb
1-8 UNC	.606	30,300	33,275	505 ft lb	555 ft lb
1-14 UNF	.678	33,900	37,290	565 ft lb	621 ft lb

*Torque figures based on assumption that excessive deformation of thread has not taken relationship between torque/tension out of its proportional range.

In actual practice a stud should not be used at its yield load. A factor of safety must be applied. It is generally recommended that studs be used at no more than 60% of yield. However, factor of safety may vary up or down, depending on the particular application. The user will make this determination.

Formula used to calculate above data is as follows:

where

D = Nominal Thread Diameter

A = Mean Effective Thread Area (META)¹

S = Tensile Stress in psi

L = Tensile Load in Pounds

T = Torque in Inch Pounds

Y = Yield Stress in psi

Z = Yield Load in Pounds

Ultimate Tensile L = SA
Yield Z = YA

Ultimate Torque T = .2 x D x L
Yield Torque T = .2 x D x Z

1. META are used instead of root area in calculating screw strengths because of closer correlation with actual tensile strength. META are based on mean diameter, which is the diameter of an imaginary co-axial cylinder whose surface would pass through the thread profile approximately midway between the minor and pitch diameters.

Table 7
Approximate Tensile and Torque Strengths of
Capacitor Discharge Welded Studs

Stud Thread Designation	Tensile Yield Load, lb	Maximum Wrench Torque, in. lb		
Annealed Carbon Steel				
# 6-32	500	9		
# 18-32	650	17		
# 10-24	900	25		
# 10-32	1000	29		
# 1/4-20	1300	55		
Types 304 and 305 Stainless Steel				
# 6-32	930	16		
# 8-32	1360	31		
# 10-24	1630	48		
# 10-32	1960	60		
# 1/4-20	3000	120		
F-22 Aluminum Alloy (5000 Series)*				
	Minimum Torque Value		Minimum Tensile Load	
Stud Size	ft-lbf	J	lb	kg
6 - 32	3.5	4.7	375	170
9 - 32	7.5	10.0	635	290
10 - 24	10	13.5	770	350
1/4 - 20 U	40	54	1360	620
5/16 - 18 UN	70	95	2300	1045

*Refer to ANSI/AWS D1.2-90

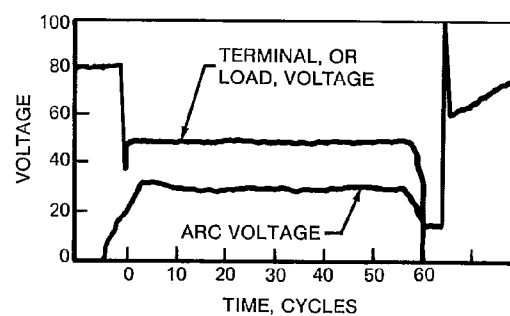
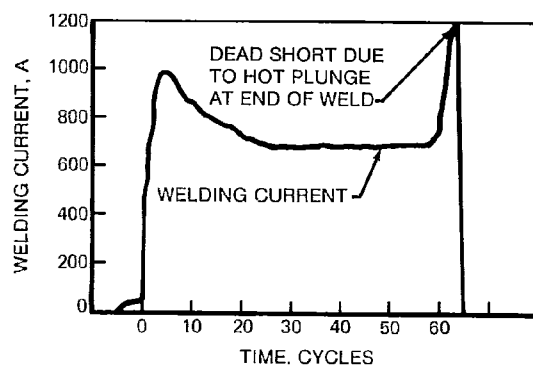


Figure 10 — Oscilloscope Traces of Current and Voltage in Arc Stud Welding

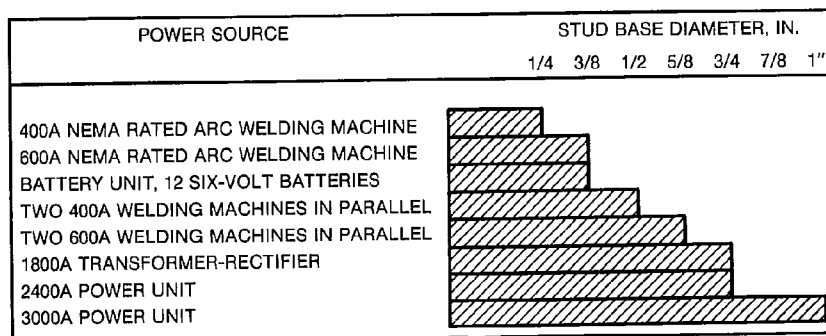


Figure 11 — Arc Stud Welding Capacity for DC Power Sources

higher for stud welding. Cable voltage drop is greater with stud welding than arc welding because of the higher current requirements.

The duration of a stud weld cycle is generally less than one second. Therefore, load ratings and duty-cycle ratings are made on the basis of one second. The rated output of a machine is its average current output at 50V for a period of one second. Thus, a rating of 1000A at 50V means that during a period of one second, the current output will average 1000A and the terminal voltage will average 50V.

Oscillographic traces show that the current output of a motor-generator stud welding power source is higher at the start of welding than at the end. Thus, it is necessary to use the average current for rating purposes.

The duty-cycle for arc stud welding machines is based on the formula:

Duty-cycle, % = $1.7 \times \text{no. of 1 second loads per minute}$ where the one second load is the rated output.

If the machine can be operated six times per minute at rated load without causing its components to exceed their maximum allowable temperatures, then the machine would have a 10 percent duty-cycle rating.

Transformer-rectifier type power sources developed specifically for stud welding are of two basic types: (1) those that require a separate stud welding control unit, and (2) those that incorporate the stud welding gun control and timing circuits as an integral part of the power source. This latter type is generally referred to as a *power-control unit*. Power-control-type units utilize silicon controlled rectifiers for initiating and interrupting the weld current, and solid-state components for gun control and timing circuitry. Power-control type units are available for both three-phase and single-phase incoming power. The three-phase units are preferred for stud welding larger diameter studs because they provide a balanced load on the incoming power line. Single-phase units are low cost, portable types for stud welding small diameter studs 1/2 in. (12.7 mm) diameter and under.

The trend in power sources has been towards totally integrated units, i.e., power-control units. This has been made possible by the development of high-power solid-state switching devices, and these units produce extremely accurate current and time parameters. Some of this type power-control units are designed to include a positive current feedback that monitors and maintains or regulates desired current (as set on unit) irrespective of changes in cable length or the cable resistance due to heat buildup. This type unit is recommended when the ultimate in current and time control is necessary. Figure 1A shows a typical equipment setup for arc stud welding steel with an integrated power-control unit.

Nonregulated power sources may be severely hampered by the use of either very small or very long cables. This factor is often overlooked when the problem of inadequate welding power arises. When examining cable length, the total cable in the welding circuit must be taken into account. For any given length of cable, the welding current can be increased approximately 10 percent by using a cable of the next larger diameter.

5.1.2 Control Units. The control unit, which regulates arc duration, consists basically of a contactor suitable for interrupting the welding current and a timing device with associated electrical components. The weld timing device may be graduated in terms of cycles (60 Hz), seconds, or number referenced settings. Weld times may vary from 0.05 to 2 seconds, depending on stud diameter.

The tests made to determine the curves in Figure 12 were run with a 2000A power supply at maximum settings. Only the cable length and cable size were changed. In this case, the maximum welding current was 2360A with 30 ft (9 m) of AWG #1 cable. When the same size of cable was increased to 180 ft (55 m), the current decreased to 1450A. When 180 ft of #4/0 cable was used, the current was 2050A, a decrease of only 13 percent. Thus, significantly larger welding cable should be used.

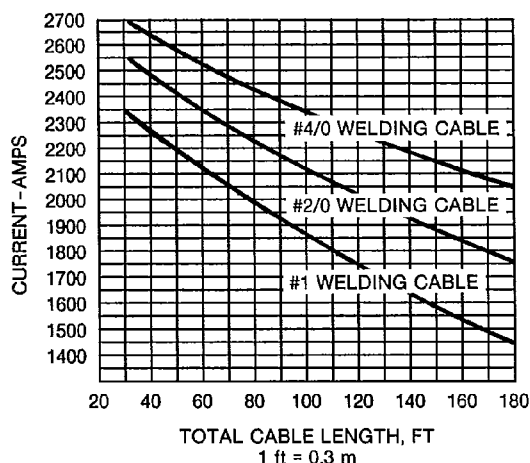


Figure 12 — Effect of Cable Size and Length on Available Welding Current from a 2000A Power Source

Size and weight of control units vary with the stud diameter being welded. A typical control unit for welding studs up through 1/2 in. (12.7 mm) diameter will weigh approximately 30 lb (14 kg), whereas a unit for welding studs 5/8 in. (15.9 mm) and larger may weigh approximately 80 lb (36 kg).

5.1.3 Arc Stud Welding Guns. There are two basic types of stud guns: portable and fixed. A portable or "hand-held" stud gun, which resembles a pistol (see Figure 13), is made of tough plastic material and weighs between 4 1/2 and 9 lb (2.4 to 4.1 kg), depending on the model. A small stud gun is used for studs from 1/8 in. (3.2 mm) through 1/2 in. (12.7 mm) diameter. A larger stud gun is used for studs up through the 1 1/4 in. (31.8 mm) diameter. The larger gun can be used for the entire stud range; however, where only small diameter studs are used, it is advantageous to use the smaller, lightweight gun.

A stud gun consists basically of a body; a mechanism to lift the stud, and then plunge it into the weld pool; a chuck or stud holder; an adjustable support for the ferrule holder or grip; and cables. Chucks and ferrule holders are easily changed. This permits welding of various stud diameters with the same stud welding gun.

A fixed or "production" gun is mounted on an automatic positioning device and is usually air operated and electrically controlled. The workpiece is positioned under the gun with locating fixtures. Multiple gun installations may be used, depending on the application and production rate desired.

5.2 Capacitor Discharge Stud Welding Equipment

5.2.1 Control-Power Unit. A control-power unit supplies the welding current, and consists basically of a bank of capacitors and the necessary circuitry for charging and discharging the capacitors. Variable discharge currents (welding currents) are obtained by varying the charge voltage on the capacitors.

Portable and stationary-type units are available for operation on 115V, single-phase, 60 Hz alternating current (ac) power. Heavy-duty production units operate on 230 or 460V single-phase or three-phase power.

The capacitance, or output rating, of the units ranges from 20 000 to 200 000 microfarad. Solid-state devices and controls are utilized in the control-power units to provide the necessary precise timing functions.

A typical portable-type control-power unit having a capacitance of 40 000 microfarads weighs approximately 70 lb (32 kg), and a heavy-duty stationary or production-type unit with 200 000 microfarad capacitance weighs several hundred pounds.

5.2.2 Stud Welding Guns. Portable or handheld stud guns range in weight from approximately 3 to 5 lb (1.4 to 2.3 kg). By changing the chucks and spark shielding accessories, one-size gun will handle the full range of capacitor discharge stud diameters.

Production or fixed-type stud guns, mounted on automatic positioning devices, can be extensively automated and are capable of welding up to 60 studs per minute.

5.3 Automatic Feed Systems. Automatic stud feed systems are available for both the arc stud welding and capacitor discharge stud welding methods, using both portable and fixed welding guns, and can be interfaced with robotic installations. Studs are automatically oriented in a parts feeder, transferred to the gun (usually through a flexible feed tube), and loaded into the welding gun chuck. Depending on the stud welding method, stud dimensions and applications, weld rates up to 45 studs per minute may be achieved.

6. Stud Welding Low-Carbon and Austenitic Stainless Steels

6.1 Base Metal Preparation

6.1.1 Preparation for Arc Stud Welding. The arc is normally of sufficient intensity and duration to burn or vaporize thin contaminant layers such as light coatings of paint, scale, rust, or oil. However, initial metal-to-metal contact must be made between the stud and work to draw a welding arc. Most controllers provide a high-voltage pilot arc to facilitate arc initiation. A center punch or other mechanical means must often be used to penetrate a thick coating.

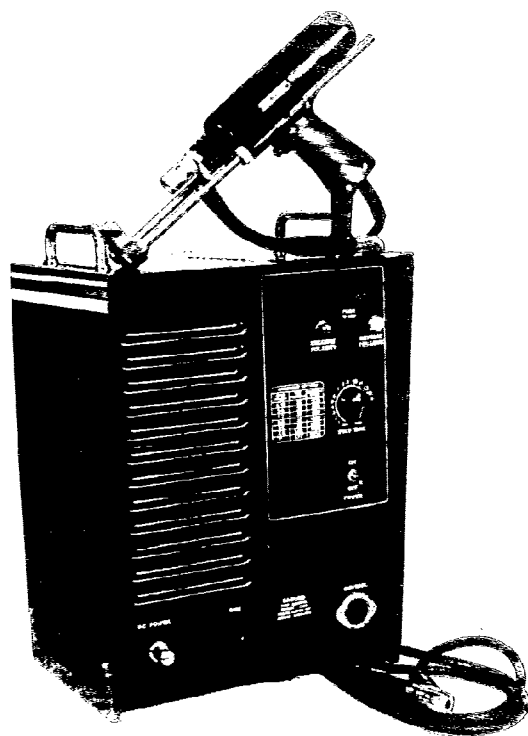


Figure 13 — Portable Arc Stud Welding Equipment

Heavy coatings of paint, rust, scale, and grease, as well as metallic contaminants such as zinc and cadmium, must be completely removed from the weld area. This can be accomplished by mechanical means (milling, blasting, grinding, and wire brushing) or chemical methods, or both. Oil and grease can usually be wiped off with a dry cloth. Solvents may sometimes be required. Test welds should be made to determine that the cleaning method is satisfactory.

It may be possible in special applications to weld through light plating and galvanized coatings using special welding procedures. Stud manufacturers can provide procedures and test data for welding studs to plated or painted metal decking.

6.1.2 Preparation for Capacitor Discharge Stud Welding. The short duration (under 20 ms) of the capacitor discharge arc requires cleaner surface areas than for arc stud welding. All paint, scale, rust, and grease must be removed from the surface prior to stud welding.

The percussive nature of the capacitor discharge arc can expel thin metallic coatings, such as those applied by electroplating and galvanizing. Therefore, satisfactory

welding can usually be accomplished on clean surfaces of this type.

A wetting solution can be applied to the weld surface to improve weld appearance and control the high-intensity welding arc. The stud supplier should be contacted for appropriate information.

6.2 Welding Requirements

6.2.1 Electrical Arrangement. Arc stud welding of steel should be performed with direct current, electrode negative (DCEN) using an arrangement similar to that shown in Figure 1. Capacitor discharge stud welding should be performed using the electrical arrangement recommended by the equipment manufacturer.

6.2.2 Work Connections. Electrical connections with the work can have significant effects on weld quality. In most cases, simply attaching the work cable securely to a clean area on the work will be adequate. However, the shape of the workpiece, specific stud location, and magnetic influence of the current path through the work can create "arc blow," uneven burnoff, and poor weld quality. Typical problems arise when welding near the edge of a part or on a long part, especially with a single work connection. A typical solution might be symmetrical contacts on opposite sides of a stud location. When the contact location appears to be causing welding problems, the equipment manufacturer should be consulted.

6.2.3 Equipment Setup. The stud gun should be set up in accordance with the manufacturer's recommendations.

6.2.4 Positions of Welding. Studs may be welded to flat, vertical, and overhead surfaces.

6.2.5 Vertical Welding of Rectangular Studs. When welding rectangular weld base studs to a vertical surface they should be positioned with the rectangular base as shown in Figure 14(A) to obtain optimum weld consistency. The orientation in Figure 14(B) is not recommended because the welds are prone to incomplete fusion and undercut.

6.3 Welding Technique for Steels

6.3.1 Arc Stud Welding

(1) The welding current, weld time, and stud gun adjustments should be set as recommended in Table 8 for the weld base diameter. After inserting the stud into the stud gun, the ferrule should be placed over the stud base and seated against the ferrule holder. The leg(s) should be adjusted so that the stud extends the required plunge distance beyond the ferrule, as recommended by the equipment manufacturer.

(2) The stud gun should be held perpendicular to the work surface, and depressed until the ferrule is firmly seated against the work.

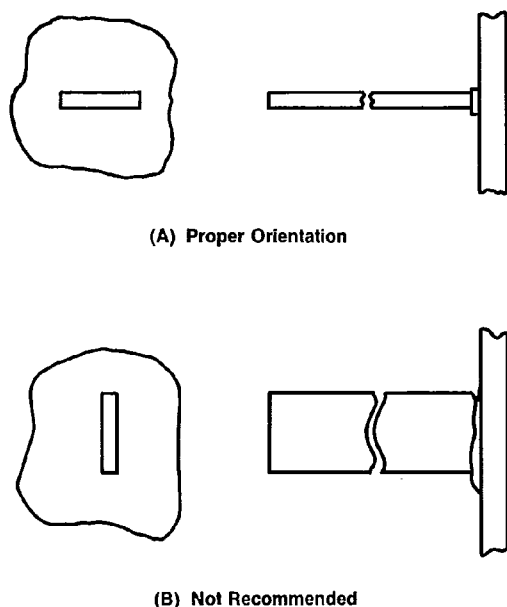


Figure 14 — Recommended Orientation for Welding Rectangular Studs to a Vertical Surface

(3) The trigger on the stud gun should then be actuated. The stud gun should not be moved during the welding cycle, and after the welding cycle has been completed, it should be held in position momentarily to allow the molten weld metal to solidify and then withdrawn.

(4) The ferrule should be removed from the stud, and the weld should be visually inspected. Figure 15 shows the appearance of acceptable and unacceptable welds. A weld with proper flash around the periphery is shown in Figure 16.

Welding conditions for rectangular studs are based on weld base dimensions and area. The welding conditions normally used for a round weld base of comparable area can be used for a rectangular stud. The welding procedures should be qualified by appropriate examination and testing. Comparable rectangular and round base studs are listed in Table 9.

Minimum plate thicknesses to which rectangular studs can be welded are generally the same as for a round base of comparable area. (See Table 3.)

6.3.2 Capacitor-Discharge Stud Welding

(1) The control-power unit is set as recommended by the manufacturer for the stud size and material. The stud is inserted into the gun.

(2) The stud gun is positioned perpendicular to the work surface. Then, the trigger is actuated. The stud gun should not be moved during the welding cycle.

**Table 8
Typical Stud Welding Conditions for Joining Low Carbon and Stainless Steel Studs to Similar Base Metals^a**

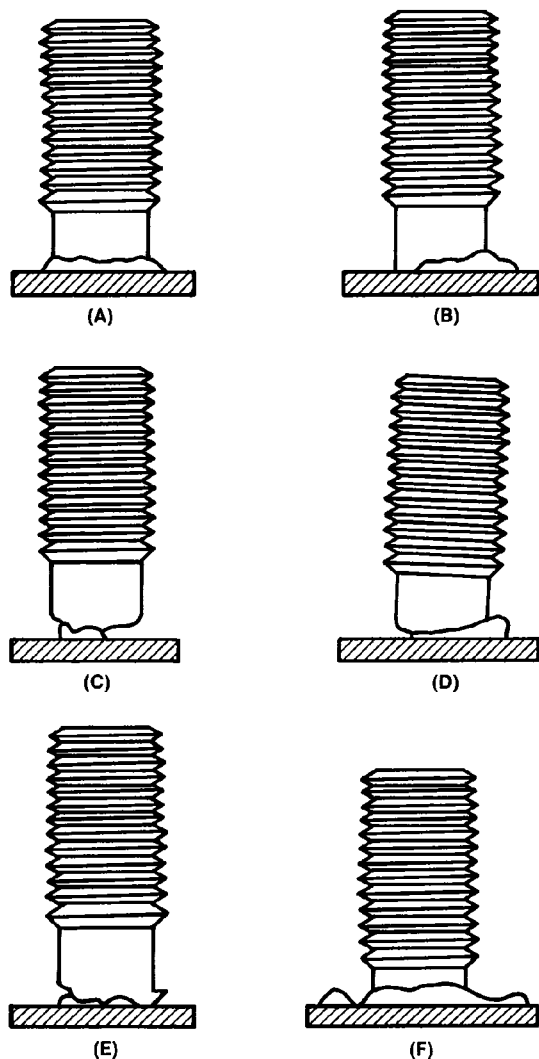
Stud Base Diameter			Welding Downhand				Welding Overhead				Welding to a Vertical Surface ^b			
			Welding Current	Weld Time, Seconds	Lift, in.	Plunge, in.	Welding Current	Weld Time, Seconds	Lift, in.	Plunge, in.	Welding Current	Weld Time, Seconds	Lift, in.	Plunge, in.
in.	mm	Area, in. ²	A				A				A			
0.250	6.4	0.0491	450	.17	0.062	0.125	450	.17	0.062	0.125	450	.17	0.062	0.125
0.312	7.9	0.0767	500	.25	0.062	0.125	500	.25	0.062	0.125	500	.25	0.062	0.125
0.375	9.5	0.1105	550	.33	0.062	0.125	550	.36	0.062	0.125	600	.33	0.062	0.125
0.437	11.1	0.1503	675	.42	0.062	0.125	675	.42	0.062	0.125	750	.33	0.062	0.125
0.500	12.7	0.1964	800	.55	0.062	0.125	800	.55	0.062	0.125	875	.46	0.062	0.125
0.625	15.9	0.3068	1200	.67	0.093	0.187	1200	.67	0.062	0.187	1275	.60	0.062	0.187
0.750	19.1	0.4418	1500	.84	0.093	0.187	1500	.84	0.062	0.187	Not Recommended			
0.875	22.2	0.6013	1700	1.00	0.125	0.250	1700	1.00	0.062	0.250	Not Recommended			
01.000	25.4	0.7854	1900	1.40	0.125	0.250	2050	1.20	0.062	0.250	Not Recommended			

Notes:

a. These welding conditions normally produce satisfactory results; they may be modified to meet specific application or jobsite conditions.

b. Stud or weld base diameters through and including 5/8 in. (15.9 mm) diameter can be expected to perform well under almost any type of service. Good results have also been obtained with 11/16 in. (17.3 mm) diameter weld base studs; however, very close control of setup and procedure should be observed. Special ferrules are required when welding large diameter studs to a vertical surface. For specific recommendations, contact the stud manufacturer.

(3) The weld should be visually inspected after withdrawing the stud gun. Examples of satisfactory and unsatisfactory welds are shown in Figure 17.



- (A) Satisfactory stud weld with a good flash formation
- (B) Stud weld in which plunge is too short
- (C) Hang-up
- (D) Poor alignment
- (E) Stud weld made with insufficient heat
- (F) Stud weld made with excessive heat

Figure 15 — Satisfactory and Unsatisfactory Arc Stud Welds

7. Stud Welding Aluminum Alloys

7.1 Base Metal Preparation. Prior to welding, surface areas to which studs will be welded should be clean and free of foreign matter including the following:

- (1) Paint
- (2) Moisture
- (3) Heavy oxide film
- (4) Oil, grease, indelible markings, etc.
- (5) Anodic coatings

Cleaning may be accomplished by mechanical means (milling, stainless steel wire brushing), chemical methods, or both. Oil, grease, and similar contaminants should be removed with a suitable, safe solvent. (The use of chlorinated hydrocarbons should be avoided.) A heavy oxide film may require removal by chemical means. Welding should take place within eight hours after cleaning.

7.2 Shielding Gas. Shielding gas for arc stud welding and drawn-arc capacitor discharge stud welding is generally argon of at least 99.95 percent purity. Helium may be used with large studs to take advantage of the higher arc energy. The gas should be directed to the weld area with an adaptor foot, and permitted to flow only while the gun is held against the work in the welding position. The shielding gas flow rates used should be those recommended by the stud manufacturer. Shielding gas is not required with the use of either contact or gap capacitor discharge welding.

7.3 Welding Requirements

7.3.1 Electrical Arrangements. Arc stud welding of aluminum should be performed with direct current, electrode positive (DCEP). The proper arrangement is shown in Figure 18. Capacitor discharge stud welding should be performed using the electrical hook-up recommended by the manufacturer.

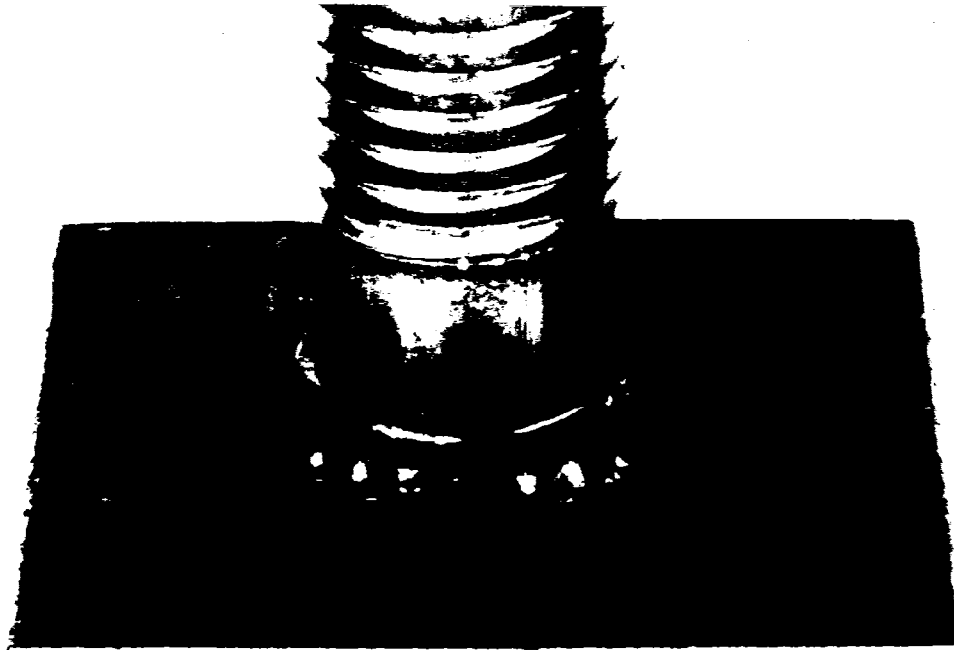
7.3.2 Equipment Setup. The stud gun should be set up in accordance with the recommendations of the equipment manufacturer. An arc stud welding gun should be equipped with a dampening device to control the plunge rate of the stud at the completion of weld time.

7.3.3 Positions of Welding. Studs may be welded to flat, vertical, and overhead surfaces.

7.4 Welding Technique for Aluminum

7.4.1 Arc Stud Welding

(1) The welding current, weld time, and shielding gas flow should be set as recommended in Table 10. The welding current should not be switched off until the stud



**Figure 16 — Arc Stud Weld with
Proper Flash Indicative of a Good Weld**

**Table 9
Comparable Rectangular and Round Studs**

Dimensions of Standard Rectangular Base Studs		Base Area, in. ²	Comparable Round Stud Base	
in.	mm		Diameter, in.	Area, in. ²
1/8 x 1/4	3.2 x 6.4	0.0312	0.215	0.0363
1/8 x 3/8	3.2 x 9.5	0.0468	0.250	0.0491
1/8 x 1/2	3.2 x 12.7	0.0625	0.275	0.0594
1/8 x 5/8	3.2 x 15.9	0.0781	0.312	0.0767
3/16 x 5/8	4.8 x 15.9	0.1168	0.375	0.1105
3/16 x 3/4	4.8 x 19.1	0.1402	0.437	0.1503
3/16 x 7/8	6.8 x 22.2	0.1636	0.448	0.1576
1/4 x 1/2	6.4 x 12.7	0.1250	0.375	0.1105
1/4 x 3/4	6.4 x 19.1	0.1875	0.500	0.1964
1/4 x 1	6.4 x 25.4	0.2500	0.562	0.2485
1/4 x 1-1/4	6.4 x 31.8	0.3125	0.680	0.3632

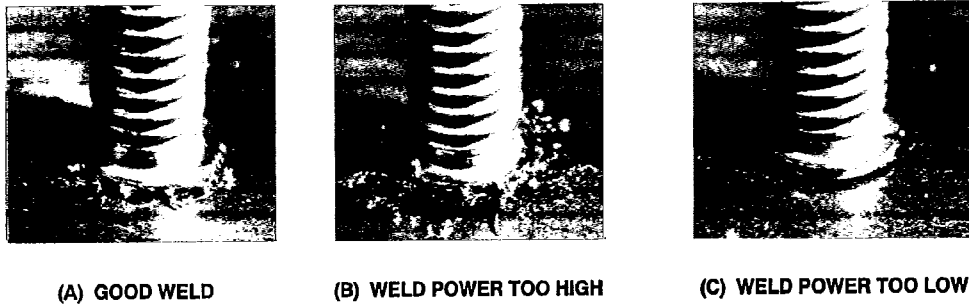


Figure 17 — Examples of Satisfactory and Unsatisfactory Capacitor Discharge Stud Welds

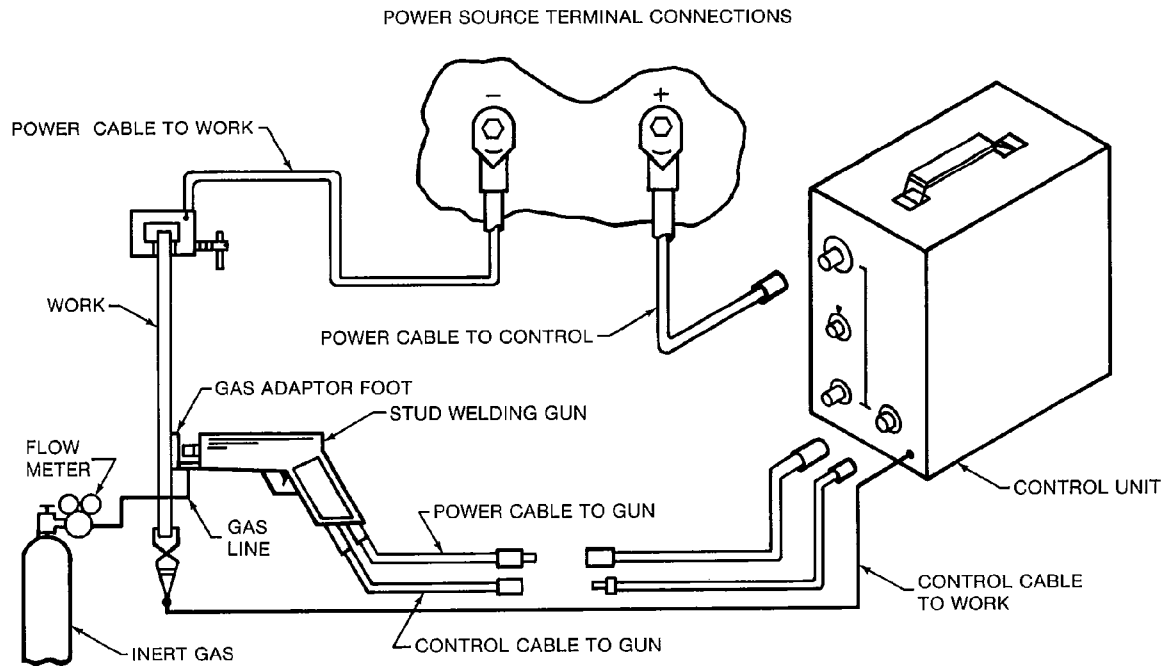


Figure 18 — Equipment Setup for Arc Stud Welding of Aluminum

Table 10
Typical Welding Conditions for Arc Stud Welding of Aluminum Alloys^a

Stud Base Diameter		Weld Time, cycles (60 Hz)	Welding Current, ^b amps	Shielding Gas Flow ^c		Plunge, in. ^d
in.	mm			CFH	litre/min.	
1/4	6.4	15	250	15	7.1	1/8
5/16	7.9	20	370	1	57.1	5/32
3/8	9.5	25	540	20	9.4	5/32
7/16	11.1	30	570	20	9.4	1/8
1/2	12.7	43	640	20	9.4	1/8

Notes:

- a. Settings should be adjusted to suit job conditions.
- b. The values shown are actual welding currents, not dial settings.
- c. Shielding gas — 99.95% argon.
- d. Lift — 3/32 in.

plunges into the work. After inserting the stud into the stud gun, the ferrule should be placed over the stud base and seated against the ferrule holder. The leg(s) should be adjusted so that the stud extends the required plunge distance beyond the ferrule, as recommended by the equipment manufacturer.

(2) The stud gun should be held perpendicular to the work surface with the ferrule and the shielding gas adaptor foot firmly seated against the work.

(3) The trigger on the stud gun should then be actuated and released. The stud gun should not be moved during the welding cycle, and after the welding cycle has been completed, it should be held in position momentarily to allow the molten metal to solidify and then withdrawn.

(4) The ferrule should then be removed from the stud and the weld should be visually inspected (see Figures 15 and 16).

7.4.2 Capacitor-Discharge Stud Welding

(1) The control-power unit should be set for the stud diameter as recommended by the manufacturer. The stud should then be inserted into the stud gun.

(2) The shielding gas flowmeter, if shielding gas is required, should be adjusted in accordance with Table 10. (This would only be with drawn-arc method.)

(3) The stud gun should be held perpendicularly against the work surface, and then the trigger actuated and released. The stud gun must not be moved during the welding cycle.

(4) The weld should be visually inspected after withdrawing the stud gun (see Figure 17).

8. Stud Locating Techniques

The method of locating studs depends upon the intended use of the studs and the accuracy of location

required. For applications requiring extreme accuracy, special locating fixtures and fixed (production type) stud welding setups are recommended. The extent of tooling will be a function of the required production rate as well as total production.

The simplest and most common procedure uses arc stud welding. Lay out and center punch the locations, either directly on the work or through a template. The stud is located by placing the point of the stud in the punch mark. Location tolerances of plus or minus 0.046 in. (1.2 mm) can be obtained with this method. Operator skill is always a factor in accuracy. Cover plates can be used as templates.

8.1 Locating with Templates. When a number of pieces will be stud welded, common practice is to weld directly through holes in a template. Figure 19 illustrates a template that positions the ferrule in its grip. Because of manufacturing tolerances on ferrules, the tolerance on stud location with this method is usually plus or minus 1/32 in. (0.8 mm). Figure 20 illustrates a template for the capacitor discharge method that positions the stud by locating the spark shield.

When closer accuracy and alignment are required, a tube-type template is used. The stud is located indirectly by inserting an adaptor on the gun in a locating bushing in the template. Figure 21 illustrates this type template. The template uses a hardened and ground drill jig bushing with a closely machined tube adaptor. Because standard ferrule grips are used with this adaptor, standardization of templates is possible. To weld studs of different diameters, it is only necessary to change ferrule grips. With this type template, a tolerance of plus or minus 1/64 in. (0.4 mm) can be held on stud location. This type template also maintains excellent stud perpendicularity.

8.2 Locating with Spacers. A simple spacer collar can be used to locate from previously welded studs as shown

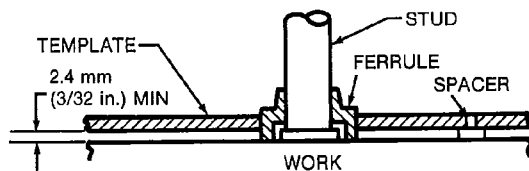


Figure 19 — Simple Template Used to Locate Studs Within $\pm 1/32$ in. (0.8 mm)

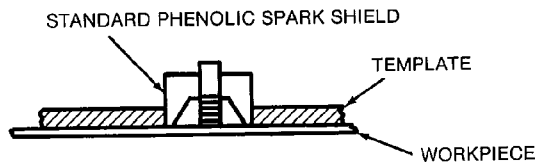
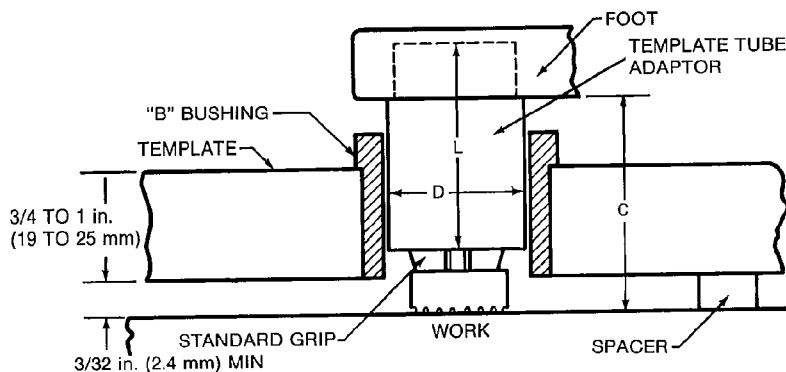


Figure 20 — Simple Template for Capacitor Discharge Welds



Stud diam., in.	Drill jig bushing, B	D, in.	C, in.	L, in.
1/4	Note 1	1.245/1.242	1.824	2.00
5/16			1.824	
3/8			1.838	
7/16			1.872	
1/2	Note 2	1.557/1.554	1.905	2.50
5/8			2.601	
3/4			2.663	
7/8	Note 3	2.120/2.117	2.605	
1			2.673	

Note 1: Acme Type "S", Group 8, S-84 1.250 in. I.D.
 Note 2: Acme Type "S", Group 9, S-95 1.5625 in. I.D.
 Note 3: Acme Type "S", H 160-20, 2.125 in. I.D.
 Note 4: 1 in. = 25.4 mm

Figure 21 — Template with Hardened and Ground Bushing and Welding Gun Adaptor

in Figure 22, or from nearby projections. Although locational tolerances will accumulate, this is a practical method of locating studs in repeating patterns, as illustrated in Figures 23 and 24.

8.3 Fixed Guns. When an application requires one or more studs welded to a fixtured workpiece, it is sometimes practical to mount the stud guns in fixed positions. An easily fabricated bracket that clamps to the gun legs is shown in Figure 25. This approach can ensure perpendicularity between stud and workpiece.

8.4 Methods of Ensuring Perpendicularity

8.4.1 Bipod Foot. The bipod foot ensures perpendicularity between stud and workpiece by three-point contact between gun and work. Figures 26 and 27 illustrate bipod foot arrangements.

8.4.2 Leg Mounted Bipods. To ensure perpendicularity of studs to a part with unusual surface contours, it is sometimes practical to use leg mounted bipods as shown in Figure 28. By adjusting the radial location and length of this type of bipod, it is possible to adapt it to most kinds of workpiece contours.

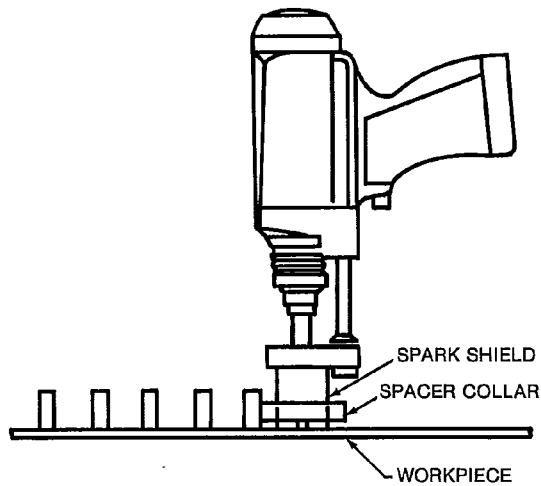


Figure 22 — Locating with Spacer

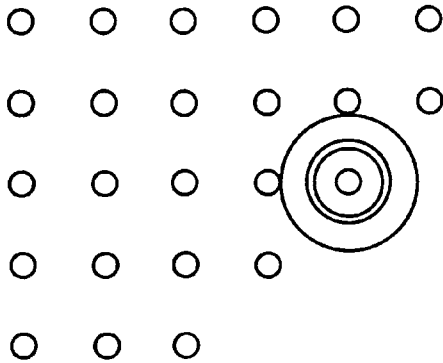


Figure 23 — Locating from Adjacent Studs

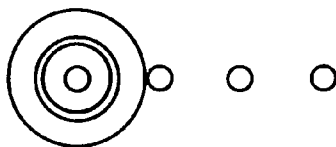


Figure 24 — Locating from Nearby Surface and Previous Stud

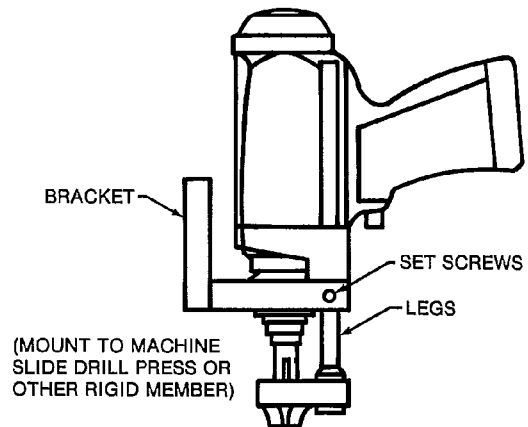


Figure 25 — Mounting Gun in a Fixed Position

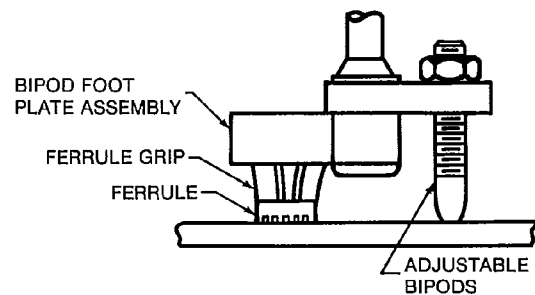


Figure 26 — Bipod Foot Plate Assembly for 1/2 in. (12.7 mm) Diameter and Smaller Studs

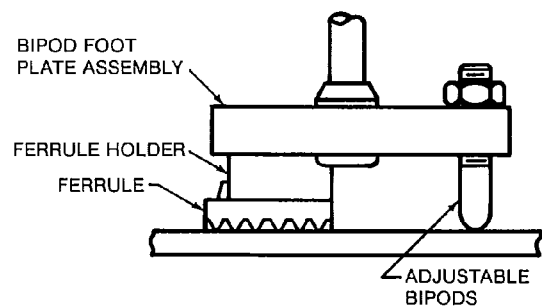


Figure 27 — Bipod Foot for 1/2 in. (12.7 mm) Diameter and Larger Shear Connector Studs

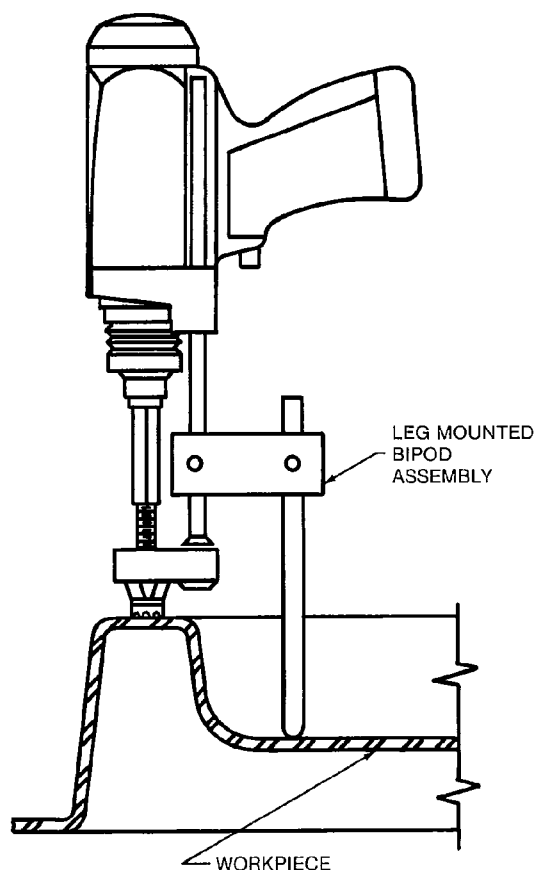


Figure 28 — Bipods for Unusual Surface Contours

8.5 Special Accessories

8.5.1 Ferrule Tube Extension. When welding through a hole or close to an obstruction, a ferrule tube arrangement can be utilized as illustrated in Figure 29.

8.5.2 Offset Assemblies. Figure 30 illustrates a typical offset assembly. Offset assemblies are generally utilized when a stud must be welded below an obstruction.

8.5.3 Ferrule Foot Plates. When welding very short studs, it is sometimes necessary to use a ferrule foot plate rather than a conventional foot and ferrule grip. Figure 31 illustrates a ferrule foot plate application.

8.5.4 Extensions, Legs, and Chucks. When welding very long studs or standard length studs to inaccessible locations, an extension similar to that shown in Figure 32 is often used. The leg extension provides a rigid and rugged assembly. Extensions are far superior to long legs.

9. Quality Control and Inspection

9.1 Steel Studs. Welded studs may be inspected visually for weld appearance and consistency, and also mechanically. Production studs can be proof tested by applying a specified load (force) on them. If they do not fail, the studs are considered acceptable. Production studs should not be bent or twisted for proof testing.

9.1.1 Visual Inspection. The weld flash around the stud base is inspected for consistency and uniformity. Lack of a flash may indicate a faulty weld. Figures 15(A) and 16 show satisfactory stud welds with a good weld flash formation. In contrast, Figure 15(B) shows a stud weld in which the plunge was too short. Prior to welding, the stud should always project the proper length beyond the bottom of the ferrule. (This type of defect may also be caused by arc blow.) Figures 15(C) and 33 illustrate "hang-up." The stud did not plunge into the weld pool. This condition may be corrected by realigning the accessories to ensure completely free movement of the stud during lift and plunge. Arc length may also require adjustment.

Figure 15(D) shows poor alignment, which may be corrected by positioning the stud gun perpendicular to the work. Figures 15(E) and 34 show the results of low weld power. To correct this problem, the ground and all connections should be checked. Also, the current setting or the time setting, or both, should be increased. It may also be necessary to adjust the arc length. The effect of too much weld power is shown in Figures 15(F) and 35. Decreasing the current setting or the welding time, or both, will lower the weld power.

9.1.2 Mechanical Testing. Mechanical tests should be made before initiation of production welding and after any equipment maintenance to ensure that the welding schedule is satisfactory. They may also be made during the production run or at the beginning of a shift to ensure that welding conditions have not changed. Arc stud welds are tested by bending the stud or by applying a proof tensile load.

Bending may be done by striking the stud with a hammer or by bending it using a length of tube or pipe, as shown in Figure 36. The angle through which the stud will bend without weld failure will depend on the stud and base metal compositions, conditions (cold worked, heat treated), and stud design. Acceptable bending should be determined when the welding procedure specification is established or from the applicable welding code. Bend testing may damage the stud; therefore, it should be done on qualification samples only.

The method used to apply tensile load on an arc welded stud will depend on the stud design. Special tooling may be required to grip the stud properly without damage, and a special loading device may be needed. A simple method that can be used for straight threaded studs is shown in

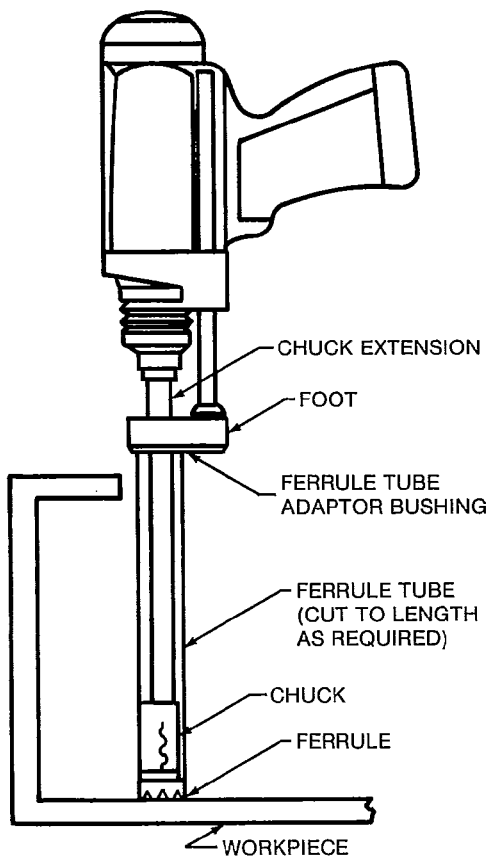


Figure 29 — Typical Ferrule Tube Extension Application

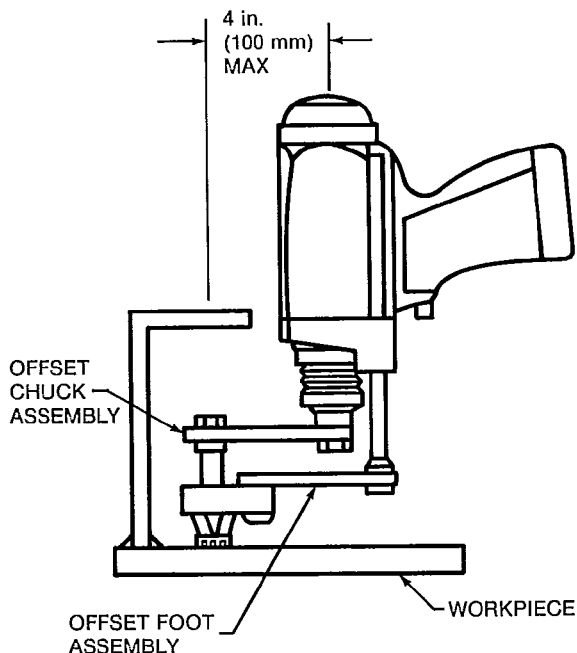


Figure 30 — Typical Offset Assembly

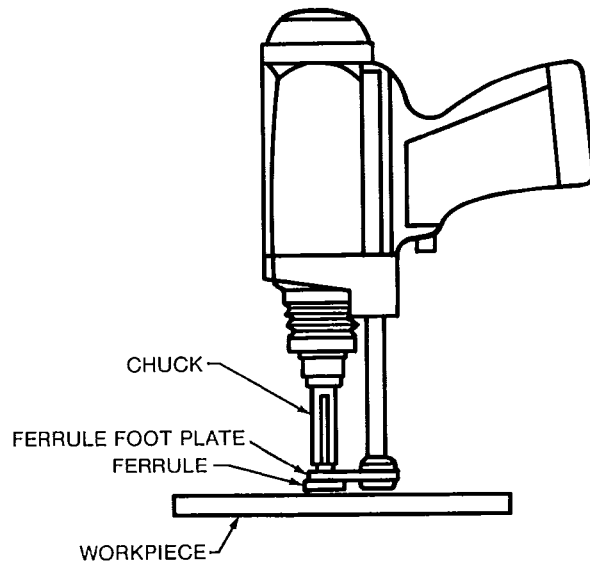


Figure 31 — Ferrule Foot Plate

Figure 37. A steel sleeve of appropriate size is placed over the stud. A nut of the same material as the stud is tightened against a washer bearing on the sleeve with a torque wrench. This applies a tensile load (and some shear) on the stud.

The relationship between nut torque, T , and tensile load, F , can be estimated using the following equation:

$$T = kFd$$

where

d = the nominal thread diameter

k = a constant related to such factors as thread angle, helix angle, thread diameters, and coefficients of friction between the nut and thread, and the nut and washer.

For mild steel, k is approximately 0.2 for all thread sizes and for both coarse and fine threads. However, the many factors that influence friction will influence the value of k . Several factors are the stud, nut, and washer materials and surface finishes, and also their lubrication. For other materials, k may have some other value because of the differences in friction between the parts.³

The torque-tension formula is useful in determining a target torque. However, the only sure way to establish the "correct" torque is through experimentation using the actual fasteners in the actual joint, or one that closely simulates it.

3. For a more detailed explanation, refer to Shigley, J. E. *Mechanical Engineering Design*, 2nd ed., 309–312. McGraw-Hill, 1972.

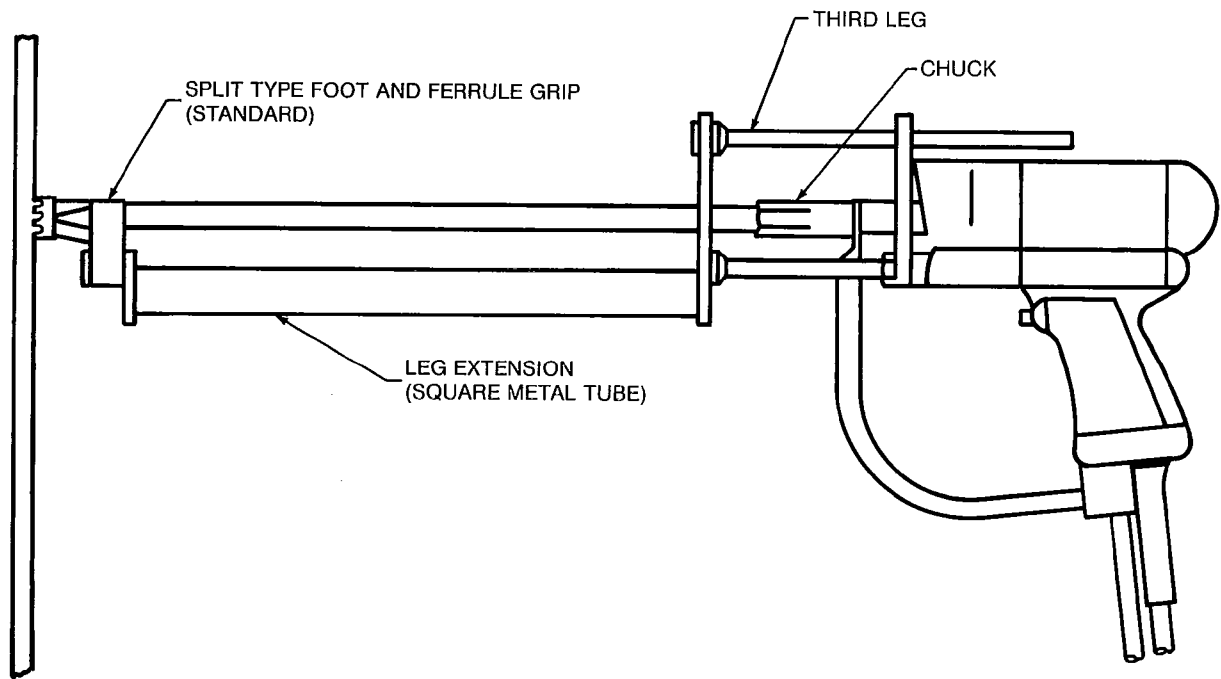


Figure 32 — Typical Extension Assembly

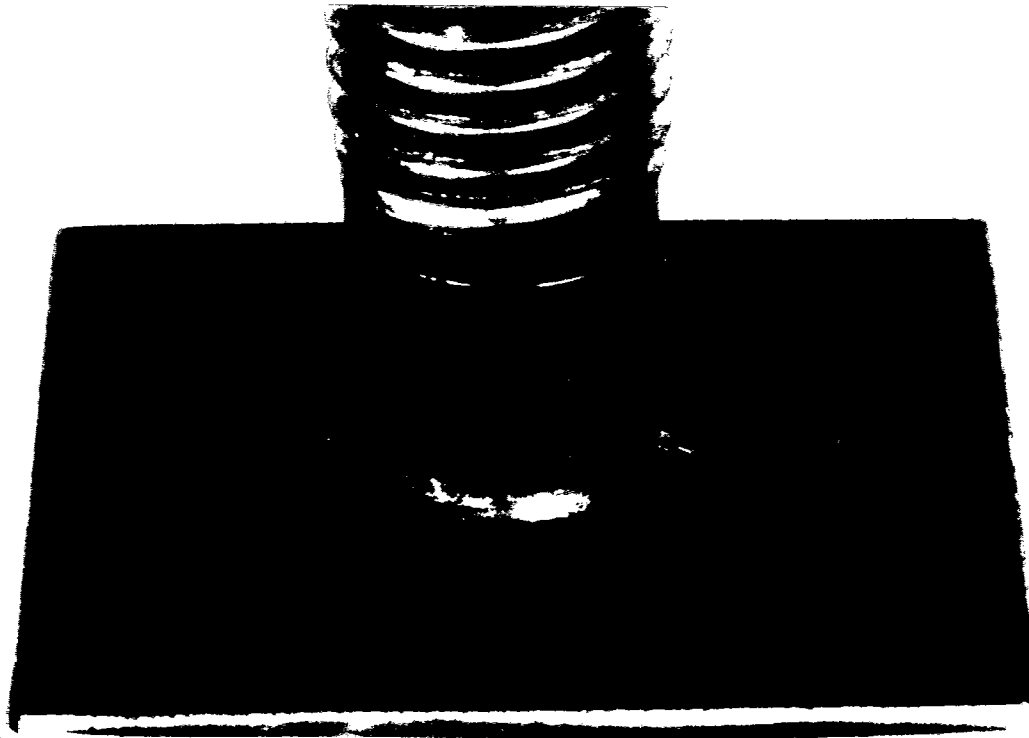


Figure 33 — Stud Hang-Up

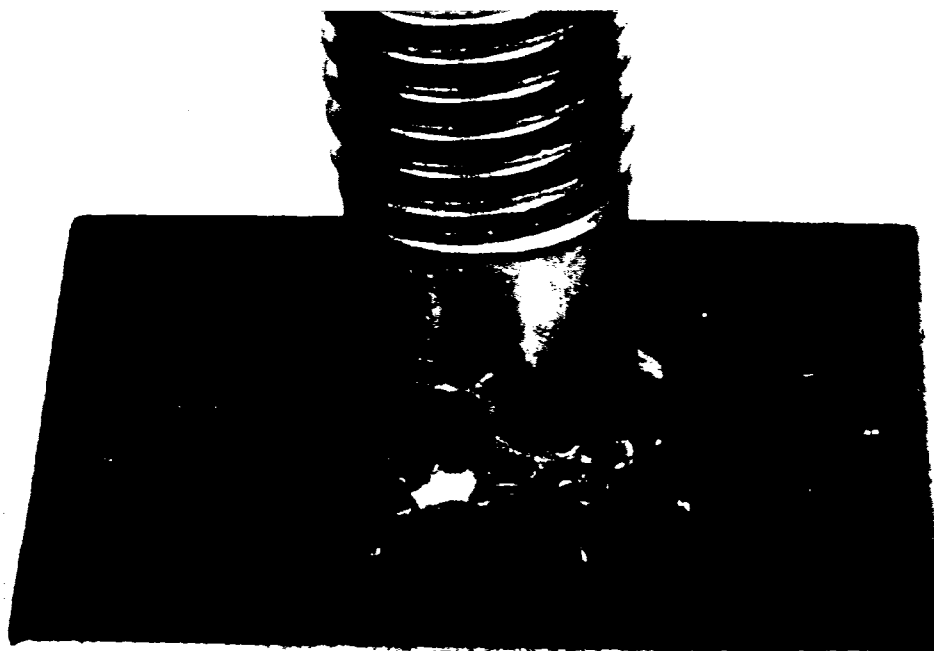


Figure 34 — Cold Weld

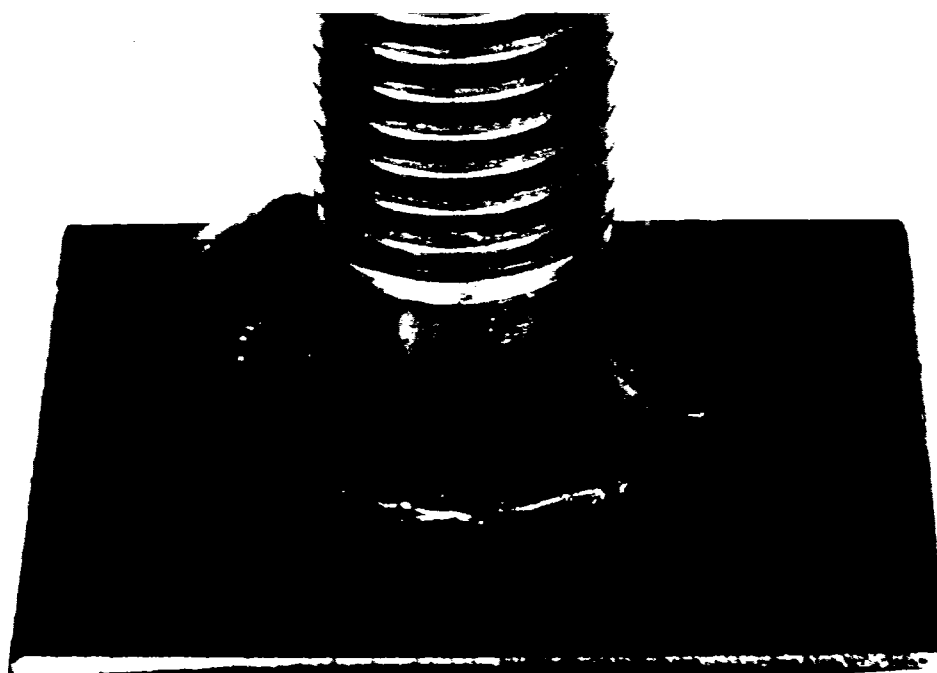


Figure 35 — Hot Weld

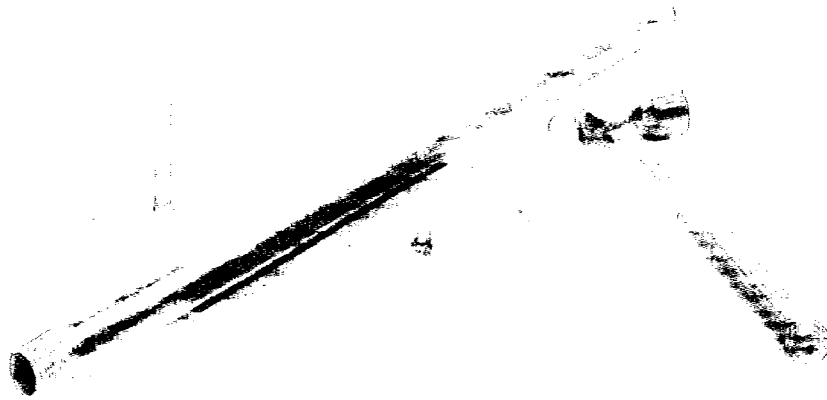
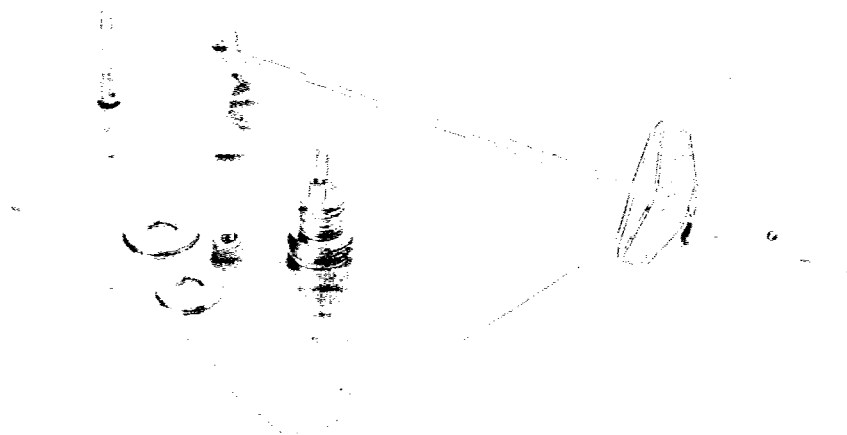


Figure 36 — Bend Test for Welded Studs to Determine Acceptable Welding Procedures



Note: A bolt can be used for an internal thread.

Figure 37 — Method of Applying a Tensile Load to a Welded Stud Using Torque — a Bolt Can Be Used for an Internal Thread

9.1.3 Replacement of Defective Studs. Defective studs should be removed and the surface repaired sufficiently to permit welding a new stud at that location or suitably nearby. Governing specifications usually require repair welds to meet all requirements of the qualified welding procedure.

9.2 Aluminum Studs

9.2.1 Visual Inspection. Acceptance of aluminum stud welds by visual inspection is limited because the appearance of the weld flash does not necessarily indicate quality. Therefore, visual inspection of aluminum stud welds is recommended only to determine complete fusion and absence of undercut around the periphery of the weld.

9.2.2 Mechanical Testing. Aluminum studs can be tested to establish acceptable welding procedures using the bend test shown in Figure 36. They should not be bent by hammer blows. If the stud bends about 10 degrees to 15 degrees from the original axis without breaking the stud or weld, the welding procedure should be considered satisfactory. Production studs should not be bent and then straightened because of possible damage to them. In this case, the torque test or separate qualification test plates may be substituted.

Torque testing of threaded aluminum studs is done in the same manner as that used for steel studs. Torque is applied to a predetermined value or until the stud fails. Typical torque tests gave the failure loads shown in Table 11. For a particular application, the acceptable proof load

Table 11
Minimum Required Torque Values
and Tension Loads for Arc Stud Welding
(F-22 Aluminum Alloy Studs—5000 Series)

Stud Base Diameter	Minimum Torque Value (lbs) Tension Test	Minimum Tensile Load (lbs) Tension Test
10-24	10	770
1/4-20	40	1360
5/16-18	70	2300
3/8-16	81	3250
7/16-14	140	4400
1/2-13	—	5950

should be established by suitable laboratory tests relating applied torque to tensile loading.

9.2.3 Replacement of Defective Studs. When failures are confined to the shanks of studs or the fusion faces, the work surface should be machined clean and flush before welding a replacement stud.

When the base metal has been pulled out in the course of stud removal, the surface should be repaired using a qualified welding procedure. The repaired surface should then be machined flush before welding a replacement stud.

10. Weld Troubleshooting

10.1 Cold Welds (See Figure 34). Cold welds are characterized by a flash around the stud base with inconsistent height. Further evidence is seen in the "starburst" or "spider leg" pattern of expelled metal shooting out of the ferrule vents and by after-weld lengths longer than expected due to insufficient stud burnoff during welding.

Cause	Remedy
A. Insufficient welding current or weld time	Refer to operating manual for correct current for stud size used.
B. Short lift distance	For studs up to 1/2 in. (12.7 mm), use 1/16 in. (1.6 mm) lift; for studs over 1/2 in. (12.7 mm), use 3/32 in. (2.4 mm) lift. Consult manual for adjustment.
C. Inconsistent lift distance	Measure lift using a scale. With stud and ferrule in place, press gun against an insulated material, trigger gun, and measure lift movement several times.

Cause	Remedy
D. Excessive plunge distance	Approximately 1/8 in. (3.2 mm) of full section of stud should protrude beyond ferrule for most applications.
E. High plunge dampening rate	If equipped with adjustable rate plunge dampener, move lever to a lower number. All others must be disassembled, cleaned, lubricated, and the cup seal resized.
F. Excessive free travel (Heavy-duty guns with adjustable plunge dampener only)	Refer to Equipment Instruction and Maintenance Manual.
G. Incorrect ferrule	Each stud size has a proper ferrule size. Refer to stud catalog for correct ferrule.

10.2 Hot Welds (See Figure 35). Hot welds are identified by a low weld flash around the stud base and an uneven distribution of expelled gas and metal pattern. Frequently, a large "blob" of molten metal at one or more points outside of the ferrule occurs. Further, the stud burnoff is excessive for the stud diameter, resulting in studs shorter than expected and excessive splash and spatter occur during the weld cycle.

Cause	Remedy
A. Excessive welding current or weld time	Refer to operating manual for correct current for stud size.
B. Lack of plunge	Approximately 1/8 in. (3.2 mm) of full section of stud should protrude beyond ferrule for most applications.
C. Slow dampening rate	This can be corrected by cleaning dampener, moving the lever to a lower number, or adjusting dampener screw, depending on equipment being used.
D. Incorrect ferrule	Every stud size has its own ferrule. Refer to stud catalog for correct ferrule for the stud.

10.3 Stud Hang-Up (See Figure 33). Stud hang-up caused by any of the stud set-up problems listed results in a portion of the stud circumference not being surrounded by a full flash. This gap in the flash frequently extends into the stud shank in a very evident undercut in the stud base area reducing the effective weld base diameter and strength. The flash height is also low and flat rather than regular and high.

Cause	Remedy
A. Short plunge	Approximately 1/8 in. (3.2 mm) of full section of stud should protrude beyond ferrule for most applications.
B. Excessive weld current or weld time	Refer to manual for correct current for stud being used.
C. Slow dampening rate	This can be corrected by cleaning dampener, moving the lever to a lower number, or adjusting dampener screw, depending on equipment being used.
D. Mechanical bind in gun	Depress chuck adaptor and release slowly. Chuck adaptor must return to the full out position without binding. If necessary, disassemble and clean gun per manual.
E. Mechanical bind in accessories or ferrule	Position foot so that the stud is centered in ferrule. If stud is off center, that can restrict the plunging motion.
F. Excessive surface contamination paint, scale, rust, galvanizing, oil, etc.	Weld areas should be clean whenever possible. Contamination causes the arc to become erratic, which can result in stud hang-up. Try welding to a clean plate to determine if contamination is causing the problem.
G. Incorrect ferrule	Every stud size has a proper ferrule. Refer to stud catalog for correct ferrule for stud being used.
H. Insufficient lift	For studs up to 1/2 in. (12.7 mm), use 1/16 in. (1.6 mm) lift; for studs over 1/2 in. (12.7 mm), use 3/32 in. (2.4 mm) lift. Consult manual for adjustment.
I. Inconsistent lift	Measure lift using a scale. With stud and ferrule in place, press gun against an insulated material, trigger gun and measure lift movement several times.

11. Safety Precautions

11.1 General. Stud welding, as with any welding process, can be dangerous if the equipment is not properly installed and maintained or if the operator does not use the process with proper safety precautions. The operator should read and understand these precautions and be trained or experienced in the installation, operation, and maintenance procedures provided in the manufacturer's manual.

11.2 Electrical. *Remember, electric shock can kill!* Properly install and use stud welding systems in accordance with the National Electrical Code NFPA-70 and local codes. Take the following safety precautions:

- Do not touch live electrical parts; be sure you are insulated from same.
- Be certain that the equipment is properly grounded and that all weld cables and connectors are in good condition. Inspect the cables, connections, etc. regularly for frays, broken insulation, insulators or other electrical hazards and repair or replace them at once.
- Do not work in wet areas or weld when you are wet.
- Wear proper clothing at all times and when gloves are necessary due to welding position, be sure that they are dry, insulated, and have no holes.

11.3 Fire Protection. Remove all combustible or volatile materials from the weld area. Although weld spatter or berries resulting from stud welding are minimal, proper precautions should be taken when welding near or through combustible materials to be sure that sparks or berries cannot reach and ignite them. Store and restrain gas cylinders properly. Be sure that they never become a part of an electrical circuit and are isolated from excessive heat or welding spatter and berries. Always have fire suppression equipment available for immediate use and know how to use it.

11.4 Vision Protection. It is recommended that eye protection be worn by the operator at all times when welding. Eye glasses with spectacle frames equipped with Shade No. 3 absorption and filter lenses and side shields are suggested. Helpers or workers within 5 ft (1.5 m) of a welding operation should wear clear safety glasses with side shields. For additional information consult ANSI Standard Z87.1.

11.5 Hearing Protection. It is recommended that proper ear protection be used when operating or working within five feet of all capacitor discharge stud welding systems. Other stud welding operations in confined environments should be evaluated for noise level and hearing protection need. Consult OSHA Standard 29 CFR, Part 1910, Subpart Q, *Welding, Cutting, and Brazing*, for additional information.

11.6 Protective Clothing. The use of protective clothing is recommended. The type of protection will vary with the stud welding process, application, weld position, and stud size being welded, but flame-resistant clothing including high boots, gloves, apron, leather leggings, etc. should be considered to protect the operator from welding spatter, arc flash, and berries if required. In all cases during welding do not wear clothing made from flammable synthetic fabrics. For information see ANSI/ASC Z49.1, *Safety in Welding and Cutting*.

11.7 Ventilation. Continuous welding in a closed area or welding and cleaning materials with paint, epoxy, galvanizing or other coatings can produce fumes that are unhealthful. Natural or forced ventilation in the welding area should be provided as necessary to prevent fume accumulation. Material Safety Data Sheets (MSDS) should be supplied by the material suppliers for materials used in the welding process and evaluated for dangerous contents that would produce toxic fumes or gases.

11.8 Other. Keep hands, clothing, tools, feet, etc. away from the weld stud, chuck and other moving parts during the weld cycle to avoid pinch points or electric shock.

11.9 Maintenance. Use extreme caution when servicing or troubleshooting any electrical component of the stud welding system. If possible, turn off all power and disconnect all electrical cables and follow the manufacturer's maintenance and service procedures. Capacitor Discharge (CD) stud welding equipment may retain a very high electrical charge in the capacitor bank even after being shut off. Follow the manufacturer's instructions for discharging or draining the capacitor bank before servicing CD equipment.

11.10 References

- (1) American Welding Society. *Arc welding safely* (pamphlet). Miami, FL: American Welding Society.
- (2) American National Standards Institute. ANSI/ASC Z49.1, *Safety in welding and cutting*. New York: American National Standards Institute (published by the American Welding Society).
- (3) ———. Z87.1, *Safe practice for occupation and educational eye and face protection*. New York: American National Standards Institute.
- (4) Occupational Safety and Health Administration. OSHA Standard 29CFR, Part 1910, Subpart Q, *Welding, cutting and brazing*. Available from Washington, DC: Superintendent of Documents, U.S. Government Printing Office.
- (5) Canadian Standards Association. CSA Standard W117.2, *Code for safety in welding and cutting*. Rexdale, Ontario: Canadian Standards Association.
- (6) National Fire Protection Association. NFPA-70, *National electrical code*. Quincy, MA: National Fire Protection Association.

Annex

(This Annex is not part of ANSI/AWS C5.4-93, *Recommended Practices for Stud Welding*, but is included for informational purposes only.)

Commonly Used Metric Conversions (Inch-Millimeter Conversion) 1 in. = 25.4 mm exactly

Inch and Millimeter Decimal Equivalents of Fractions of an Inch ^{1,2}					
in.			in.		
Fraction	Decimal	mm	Fraction	Decimal	mm
1/64	0.015	0.396	33/64	0.515	13.096
1/32	0.031	0.793	17/32	0.531	13.493
3/64	0.046	1.190	35/64	0.546	13.890
1/16	0.062	1.587	9/16	0.562	14.287
5/64	0.078	1.984	37/64	0.578	14.684
3/32	0.093	2.381	19/32	0.593	15.081
7/64	0.109	2.778	39/64	0.609	15.478
1/8	0.125	3.175	5/8	0.625	15.875
9/64	0.140	3.571	41/64	0.640	16.271
5/32	0.156	3.968	21/32	0.656	16.668
11/64	0.171	4.365	43/64	0.671	17.065
3/16	0.187	4.762	11/16	0.687	17.462
13/64	0.203	5.159	45/64	0.703	17.859
7/32	0.218	5.556	23/32	0.718	18.256
15/64	0.234	5.953	47/64	0.734	18.653
1/4	0.250	6.350	3/4	0.750	19.050
17/64	0.265	6.746	49/64	0.765	19.446
9/32	0.281	7.143	25/32	0.781	19.843
19/64	0.296	7.540	51/64	0.796	20.240
5/16	0.312	7.937	13/16	0.812	20.637
21/64	0.328	8.334	53/64	0.828	21.034
11/32	0.343	8.731	27/32	0.843	21.431
23/64	0.359	9.128	55/64	0.859	21.828
3/8	0.375	9.525	7/8	0.875	22.225
25/64	0.390	9.921	57/64	0.890	22.621
13/32	0.406	10.318	29/32	0.906	23.018
27/64	0.421	10.715	59/64	0.921	23.415
7/16	0.437	11.112	15/16	0.937	23.812
29/64	0.453	11.509	61/64	0.953	24.209
15/32	0.468	11.906	31/32	0.968	24.606
31/64	0.484	12.303	63/64	0.984	25.003
1/2	0.500	12.700	1	1.000	25.400

Notes:

1. To convert inches to millimeters, multiply the inch value by 25.4.
2. To convert millimeters to inches, divide the millimeter value by 25.4.

Document List

The following is a complete list of the documents prepared by the AWS Committee on Arc Welding and Cutting

AWS Designation	Title
C5.1	Recommended Practices for Plasma Arc Welding
C5.2	Recommended Practices for Plasma Arc Cutting
C5.3	Recommended Practices for Air Carbon Arc Gouging and Cutting
C5.4	Recommended Practices for Stud Welding
C5.5	Recommended Practices for Gas Tungsten Arc Welding
C5.6	Recommended Practices for Gas Metal Arc Welding
C5.7	Recommended Practices for Electrode Gas Welding
C5.10	Recommended Practices for Shielding Gases for Welding and Plasma Arc Cutting

For ordering information, contact the Order Department, American Welding Society, 550 N.W. LeJeune Road, P.O. Box 351040, Miami, Florida 33135. Phone: 1-800-443-9353.