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An American National Standard

Recommended Practices for Stud Welding



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Recommended Practices for Stud Welding

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American Welding Society (AWS) C5 Committee on Arc Welding and Cutting

Under the Direction of the
AWS Technical Activities Committee

Approved by the
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.

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Foreword

This foreword is not part of ANSI/AWS C5.4-93, *Recommended Practices for Stud Welding*, but is included for informational 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 Secretary, AWS C5 Committee on Arc Welding and Cutting, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

Errata

ANSI/AWS C5.4-93, *Recommended Practices for Stud Welding*

The following Errata have been identified and incorporated into the current reprint of this document.

Page 3, Paragraph 1.2.1, change from “currency” to “current” in third sentence.

Page 19, Table 8, last entry under Stud Base Diameter in inches, change “01.000” to “1.000”.

Page 23, Table 10, under Shielding Gas Flow heading, “litre/min.” should read “liter/min.”.

Page 23, Table 10, under Shielding Gas Flow, CFH heading, change “1” to “15”.

Page 23, Table 10, under Shielding Gas Flow, liter/min. heading, change “57.1” to “7.1”.

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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.

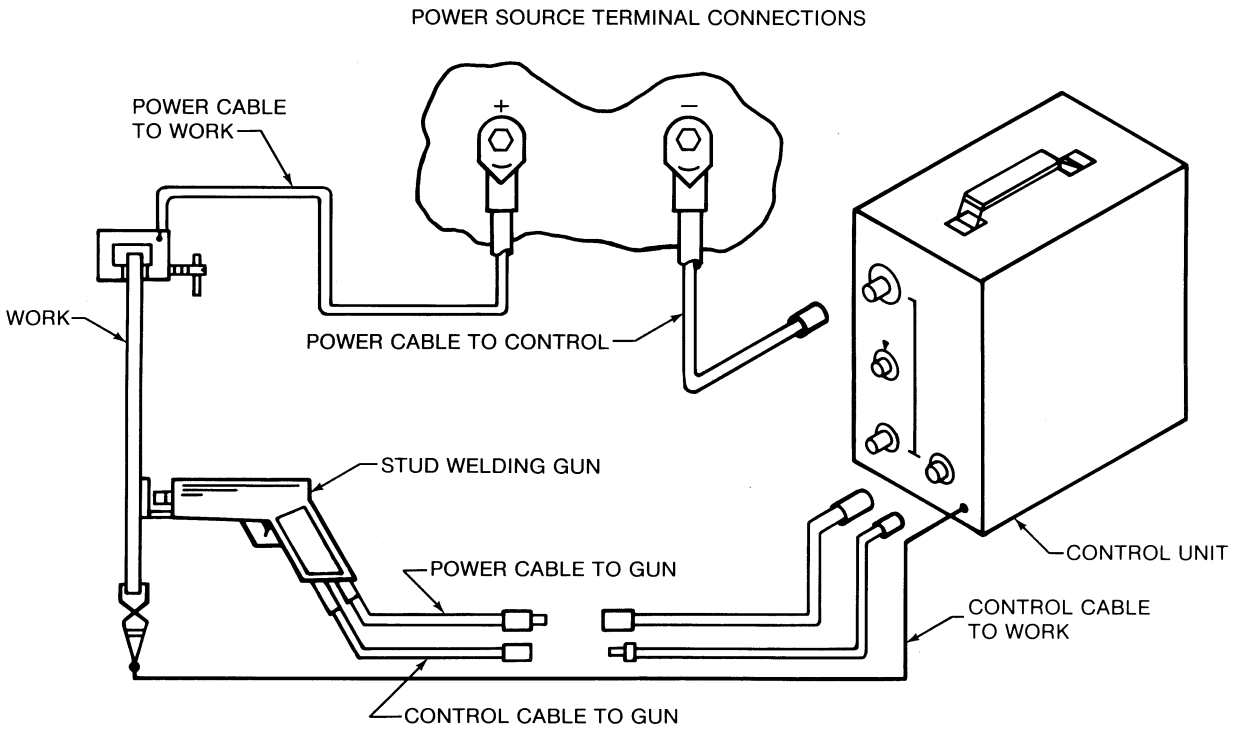


Figure 1A — Equipment Setup for Arc Stud Welding of Steel

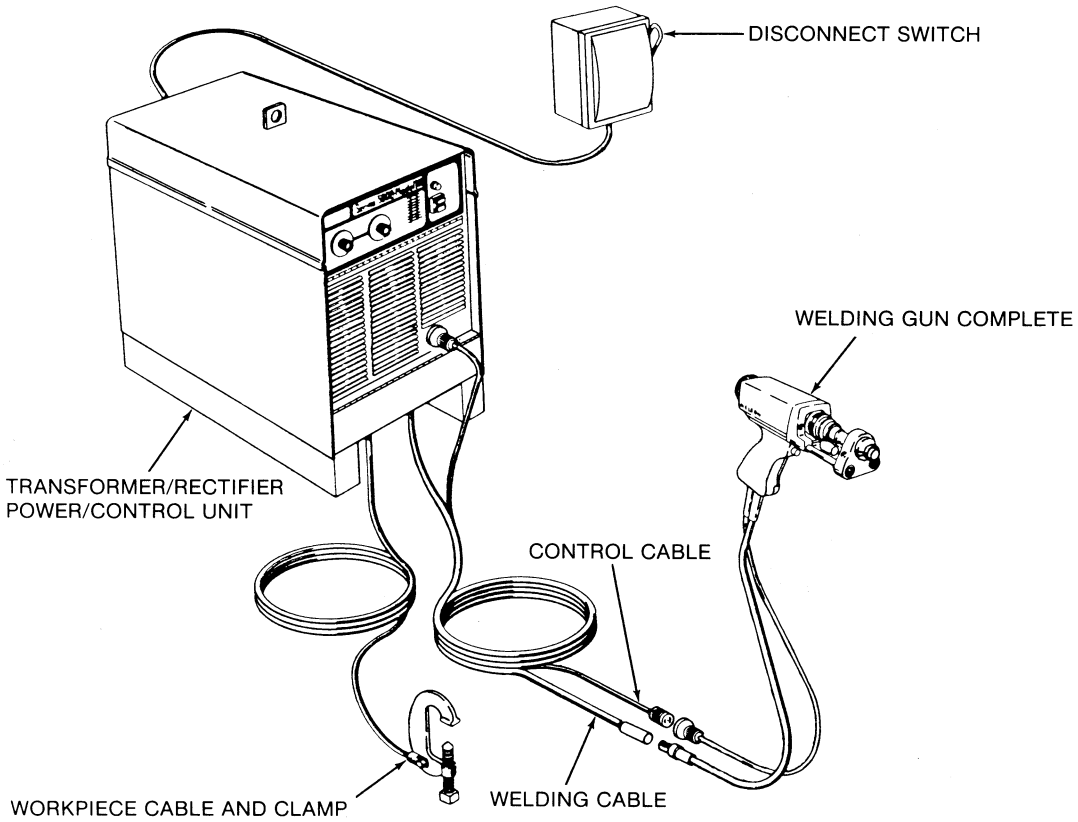
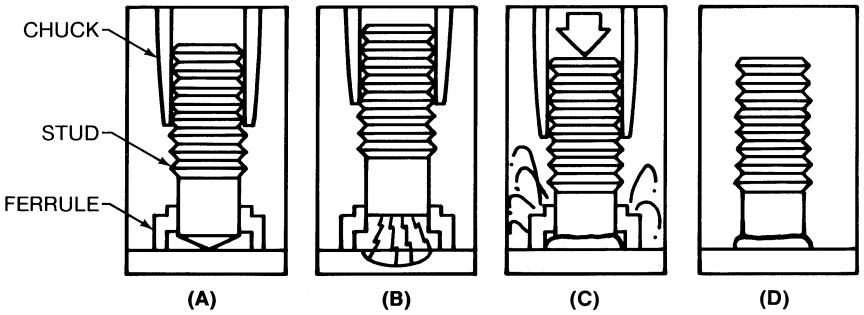


Figure 1B — Power-Control Type Power Source Setup for Arc Stud Welding of Steel



(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

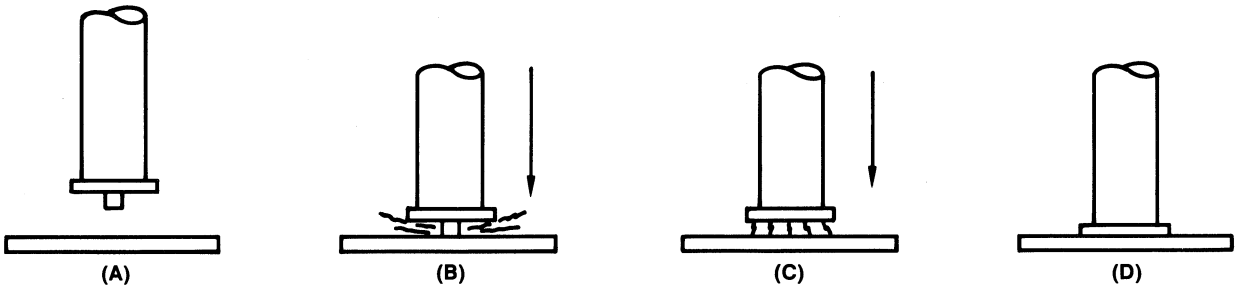


Figure 3 — Steps in Contact Capacitor Discharge Stud Welding

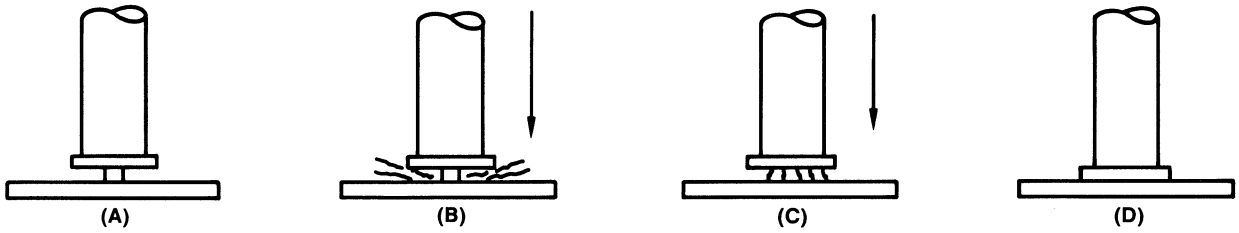


Figure 4 — Steps in Gap Capacitor Discharge Stud Welding

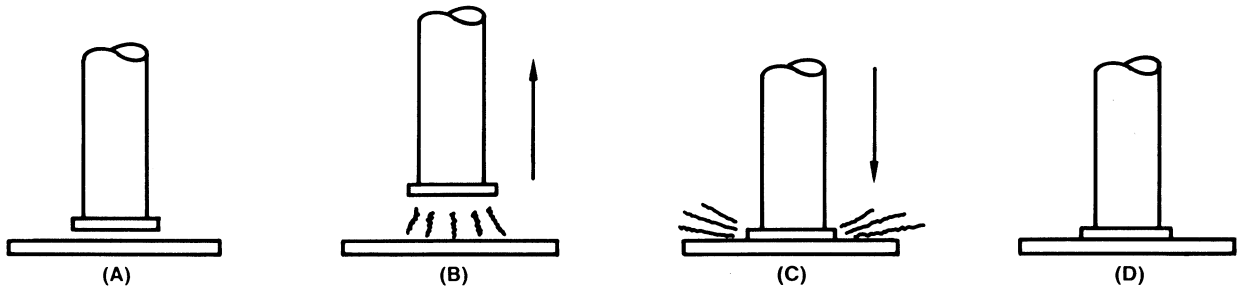


Figure 5 — Steps in Drawn-Arc Capacitor Discharge Stud Welding

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	Capacitor Discharge Stud Welding: 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	Alunimum 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]

[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