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

# Recommended Practices

# For Stud Welding

Prepared by
AWS Committee on Arc Welding and Cutting

Under 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.

# 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 12.7mm) | A | B | B |
| 1/2 to 1 in. (1.6 to 3.2mm) | 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)<br>0.015 to 0.062 in. | D | A | B |
| (0.4 mm to 1.6 mm)<br>0.062 to 0.125 in. | C | A | A |
| (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 |

**Base Metal Thickness**

For base thickness 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.

**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.

# Designing for Stud Welding

## Base Metal

### 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.

### Medium and High Carbon Steel

If medium and high- carbon steel 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 post heating after welding is recommended. In the case of tough alloy steels, either preheating or post heating may be used to obtain satisfactory results.

### Low Alloy Steel

Generally, the high strength, low alloy steels are satisfactory stud welded when their carbon content is 0.15 percent or lower. If 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 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 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.

## 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 1022ь | Low-carbon steel, AISI 1006 to 1020; stainless steel, 300 series |
| Stainless steel, 300 series, 405, 410, and 430 | Low-carbon steel, AISI 1006 to 1020; stainless steel, 300 series |
| Aluminum alloys, 5000 seriesc | Aluminum alloys, 5000 seriesc |
| **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 seriesc, 6061 and 6063 | Aluminum alloys, 1100 and 5000 series and 6061 |
| 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 |

## 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.

## 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 weldable stainless steel grades include American Iron and Steel Institute (AISI) Types 304, 305, 308, 309, 310, 316, 321, and 347. Types 304, 305, and 316 are most commonly used for stud welding.

Stainless steel studs may be welded to stainless steel or 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 studs are to be welded to mild steel, it is essential that the carbon content of the base metal not exceed 0.20 percent.

## 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 3
## 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. 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 into a flash around the base of the stud.

## Flash

When a stud is end welded, a flash forms around its base. 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 non-fusion 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 longitudinal orientation, or both, to the axis of the stud. Non-fusion on the vertical leg of the flash and small shrink fissures are acceptable.

### Table 4
### 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.) @ 50000** | **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. |
| | | | | | |
| 7/16-24 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 | 113 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 | Ultimate Torque | T = .2 x D x L |
| Yield | Z = YA | 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.

# Stud Welding Low-Carbon and Austenitic Stainless Steels

## Base Metal Preparation

### 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.

Heavy coats 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.

### Preparation for Capacitor Discharge Stud Welding

The short duration (under 20 ms) of 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.

## Welding Technique for Steels

### 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.

**(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.

### 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 5
## Typical Stud Welding Conditions for Joining Low Carbon and Stainless Steel Studs to Similar Base Metals

| Welding Downhand | | | | | | | Welding Overhand | | | | Welding to Vertical Surface | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stud Base Dia. | | Area in. | Welding Current A | Weld Time, sec. | Lift in. | Plunge In. | Welding Current A | Weld Time, Sec. | Lift in. | Plunge In. | Welding Current A | Weld Time, Sec. | Lift in. | Plunge In. |
| In. | mm | | | | | | | | | | | | | |
| 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 | .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 ferrulesare required when welding large diameter studs to a vertical surface. For specific recommendations, contact the stud manufacturer.

# Quality Control and Inspection

### Steel Studs

## Visual Inspection

The weld flash around the stud base is inspected for consistency and uniformity. Lack of a flash may indicate a faulty weld. Prior to welding, the stud should always project the proper length beyond the bottom of the ferrule.

## 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 weld studs 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.

# Safety Precautions

## 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 us 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 manufacturers manual.

## 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.

#### 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 us it.

## 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 (1.5m) of a welding operation should wear clear safety glasses with side shields. For additional information consult ANSI Standard Z87.1.

## 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, Sub-part Q, *Welding, Cutting, and Brazing,* for additional information.

## 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.*

## 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.

## 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.

## 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.

## 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.