

How to properly specify weld studs for use with the drawn arc stud welding process in structural applications.

steelwise

SOLID BOND

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STUD WELDING DOES A PRETTY GREAT job of keeping things together—and quickly.

The drawn arc stud welding process produces welds that provide a solid bond between a metal stud anchor and base metal—commonly a steel plate embedded in concrete or the top flange of a steel beam. It is a mechanized welding process that produces a weld with full fusion between the stud base and the base metal. Stud welds are stronger than the base metal or stud material alone, meaning that an engineer does not have to specifically design the strength of the weld, and the drawn arc stud welding produces consistent quality repeated over many welds. And, they can be installed in the down-hand, horizontal and overhead positions.

But there's plenty to consider when approaching a stud welding job, including specifying the correct stud type and the correct ceramic arc shield or ferrule for the intended stud application, determining the base diameter and the required after-weld length (and corresponding before-weld length) of the stud, identifying the best material for the application and determining the stud's purpose—i.e., how it is to be welded and/or applied.

The Right Stud for the Job

Let's begin with weld stud types. Weld studs come in a variety of different configurations, sizes and lengths. In composite construction the mechanical properties of embedded studs or strength under tension and shear forces are typically governed by three things: the mechanical properties of the concrete, the geometry of the concrete member around the studs and depth of embedment or stud length. Stud sizes range from very small (only a few millimeters in diameter and length) to very large (over 1 in. in diameter and 6 ft in length). Different types of studs may require specialized equipment and accessories—e.g., welding very large studs in the down-hand position can strain the limits of the welding equipment due to the physical weight of the stud.

For carbon or mild steels, the American Welding Society (AWS) D1.1 *Structural Welding Code—Steel*, lists three types of studs based on use: Types A, B and C. Type A studs are general-use studs for purposes other than shear transfer in composite construction (and therefore will not be covered in this article). Type B weld studs with a formed head and Type C deformed bar anchor studs (DBAs) are the most common studs used in composite construction. AWS D1.1 states: "Type B studs shall be studs that are headed, bent or of other configuration in

$\frac{3}{8}$ -in., $\frac{1}{2}$ -in., $\frac{5}{8}$ -in., $\frac{3}{4}$ -in., $\frac{7}{8}$ -in. and 1-in. diameter that are used as an essential component in composite beam design and concrete anchorage design." And regarding Type C: "Type C studs shall be cold-worked deformed steel bars..."

Headed weld studs are referred to as either concrete anchors or shear connectors. In the AISC *Specification for Steel Buildings* they are referred to as steel headed stud anchors, while DBAs are headless studs that resemble steel reinforcing bars or rebar. They are designed with indented deformations, rather than the protruding deformations that are typically found on rebar, which allow the studs to be gripped by standard stud welding gun accessories and welded with standard diameters of ceramic ferrules. The welding process for headed anchors and DBAs is the same and the latter are produced in many different shapes other than straight (e.g., hooked or bent) and usually require specialized welding accessories.

The terms headed concrete anchor and shear connector are used to distinguish studs by size and primary use. A headed concrete anchor is specified when the primary load is the same direction as the shank of the stud (tensile), and the shank is typically smaller than that of a shear connector. As the name implies, shear connectors are used when the forces acting between the steel and concrete are transverse (shearing) in direction. (We typically refer to a headed anchor with a $\frac{5}{8}$ -in.-diameter or smaller shank as a headed concrete anchor and studs with a $\frac{3}{4}$ -in. or greater diameter as shear connectors.)



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- ▲ The drawn arc stud welding process produces welds that provide a solid bond between a metal stud anchor and base metal.
- ▼ Ceramic ferrules are needed to properly weld drawn arc weld studs.



- ▲ A sample weld stud.
- ▼ Weld studs can be installed in the down-hand, horizontal and overhead positions.



Diameter

When choosing a stud diameter, prices increase along with diameters, though other factors should be considered as well. First of all, the failure mechanics of a composite structural assembly should be dictated by steel strength (ductile failure) rather than concrete strength (brittle failure). As stud diameter increases, the strength of the stud also increases. As the stud strength increases, the strength of the concrete may also need to be increased to maintain this ductile failure relationship of the composite structural system. If a composite system is loaded beyond intended design values, a large-diameter stud can be stronger than the surrounding concrete and the concrete can crush around the stud, losing bond between the two materials. And as the studs lose bond, the composite system will lose part, if not all, of the combined steel and concrete strength that the system relied on.

A progressive failure like this can cause a brittle, potentially catastrophic failure of the entire structural system, such as a bridge collapse. Building codes that govern composite construction and the transfer of forces between steel and concrete are written with the intent to mitigate these risks by guiding the design in such a way that if a composite system does fail, it will be a ductile failure and not a brittle failure. The ultimate failure of a ductile connection, such as an embed plate with headed studs, will be preceded by yielding of the stud material rather than failure of the surrounding concrete by pull-out, breakout or fracture.

Defects are another factor to consider when choosing the proper diameter. Welding defects, such as the phenomenon of arc blow, become greater and more frequent as stud diameter (increased weld times and current) increases. Stud diameter is also limited by the thickness of the plate or flange that the stud is being welded to. AISC *Specification* I8.1 limits the stud diameter to 2.5 times the base metal thickness while AWS D1.1 Clause limits stud diameters to 3 times the base metal thickness where the stud is welded directly to the base metal and 3 times the base metal thickness where the stud is welded through deck; check the code governing your project. AWS D1.1 considers the stud welding process to be prequalified, provided that the manufacturer has performed the proper weld base qualification testing. AWS recognizes up to a 1-in.-diameter stud. The largest diameter currently recognized by AISC for shear transfer of force from the concrete to a steel structure for welding through-deck applications, where the concrete is cast on steel form decking supported by a steel structure, is a 3/4-in.-diameter stud; 7/8-in.- and 1-in.-diameter studs are used in shear applications but are not commonly used in through-deck applications. We suggest consulting your stud manufacturer for guidance in through-deck applications using diameters exceeding 3/4 in.



- ▲ For carbon or mild steels, the American Welding Society (AWS) D1.1 *Structural Welding Code—Steel*, lists three types of studs based on use: Types A, B and C.
- ▼ Through-deck stud welding has specific stud size parameters.



- ▲ Various sizes of weld studs.
- ▼ Weld studs are produced in several materials, the most common of which are carbon or mild steel, stainless steel and aluminum.



Length

During the stud welding process, a small amount of the stud length is melted, along with some of the base material, to create the weld pool. The amount of stud consumed is typically called burn-off, melt-off or burn-off/melt-off length. The melt-off length is proportional to the amount of arc current and total time of the welding process. Since the values for current and time are proportional to the stud diameter, it is simpler to relate melt-off length to diameter.

When specifying studs, it is important to take into account the nominal melt-off length to determine the required stud length for the application. Typically, studs are ordered by specifying the length before welding (the before-weld length). For example, if the specified stud length for the project is 6 in. and the stud diameter is $\frac{3}{4}$ in., then the melt-off length is $\frac{3}{16}$ in. The length specified on your purchase order should read: $\frac{3}{4}$ in. \times $6\frac{3}{16}$ in. headed shear connector (the $6\frac{3}{16}$ -in. is the before-weld length).

The following table lists the nominal melt-off lengths for a range of standard diameter studs when they are welded directly to steel in typical down-hand applications:

Diameter Range (in.)	Nominal Melt-Off Length (in.)
$\frac{3}{8}$ to $\frac{1}{2}$	$\frac{1}{8}$
$\frac{5}{8}$ to $\frac{7}{8}$	$\frac{3}{16}$
1 to $1\frac{1}{4}$	$\frac{1}{4}$

AWS D1.1 allows studs to be fillet welded by traditional arc welding techniques, such as SMAW, GMAW or TIG. If the stud is welded by fillet welding, no melt-off will occur. If the studs are to be welded through zinc-coated metal decking, melt-off lengths of $\frac{3}{8}$ inch and greater are possible. It is important to know how the studs are going to be welded and for what type of application. For these reasons it is important to know how the studs are going to be welded and the application involved (e.g., for a through-deck application, a good rule of thumb is a burn-off of $\frac{1}{4}$ in).

Material

Weld studs are produced in several materials, the most common of which are carbon or mild steel, stainless steel and aluminum, and certain applications, environments and loading conditions require specialized materials. For example, in a highly corrosive environment, such as steel embedded in concrete piers that are subjected to cycles of wetting and drying from seawater, stainless steel studs should be used—and in cases where stainless studs are subjected to cyclic loading, annealing is required. It is also important to remember that mild steel, stainless steel and aluminum studs are covered under different AWS codes and therefore may have different requirements.

Concerning the material properties of mild or carbon steel studs, AWS D1.1 states: “Studs shall be made from cold drawn bar conforming to the requirements of ASTM A29 *Standard Specification for Steel Bars, Carbon and Alloy, Hot-Wrought, General Requirements for Grades 1010 through 1020.*” AWS D1.1 Clause 7 Table 7.1 gives the required mechanical properties for mild steel studs.

Stainless steel studs are covered under the AWS D1.6 (Stainless Steel), which states: “Studs shall be made from cold drawn bar stock

AWS D1.1/2010 Structural Welding Code – Steel, Table 7.1

		Type A ¹	Type B ²	Type C ³
Tensile Strength	psi min	61,000	65,000	80,000
	MPa min	420	450	552
Yield Strength (0.2% Offset)	psi min	49,000	51,000	–
	MPa min	340	350	–
Yield Strength (0.5% Offset)	psi min	–	–	70,000
	MPa min	–	–	485
Elongation	% in 2 in. min	17%	20%	–
	% in 5x diameter			
	min	14%	15%	–
Reduction of Area	% min	50%	50%	–

¹ Type A studs are for general purpose use other than shear transfer in composite beam design and construction.

² Type B studs are headed, bent, or of other configurations used as an essential component in composite beam design and concrete anchorage design.

³ Type C studs shall be cold-worked deformed steel bar anchors.

conforming to ASTM A 493 *Specification for Stainless Steel Wire and Wire Rods for Cold Heading and Cold Forging* or ASTM A276 *Specification for Stainless Steel Bars and Shapes*. The following 300-series alloys may be used; XM-7, 304, 305, 309, 310 and 316 or the low-carbon version thereof. Other Type 300 series may be used with the approval of the engineer; however, Type 303 shall not be used. Where studs are to be cyclically loaded, they shall be tested and furnished in the annealed condition.”

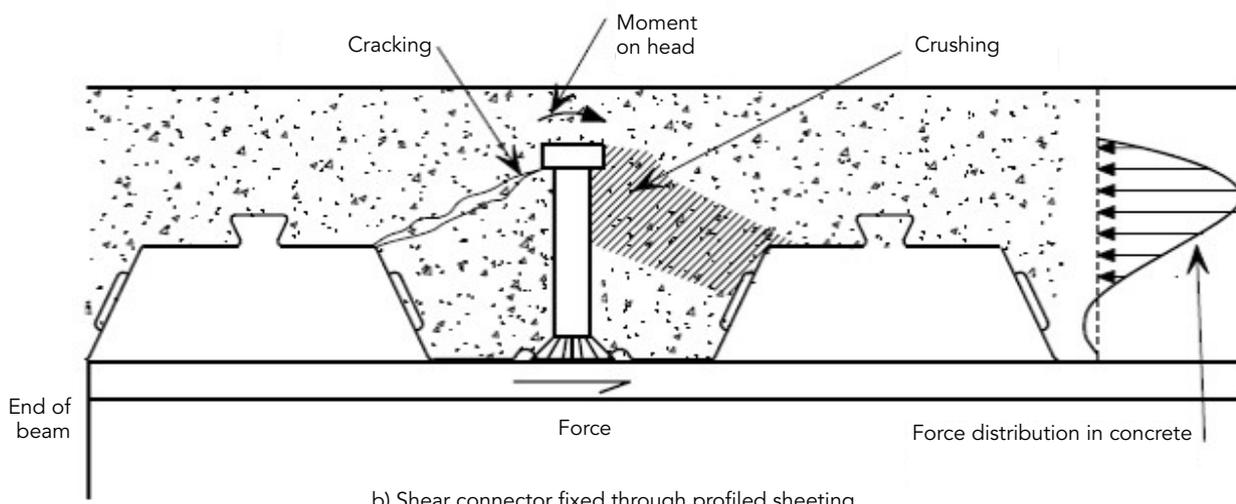
Aluminum studs are covered under AWS D1.2 (Aluminum), but are not typically used in composite construction. And note that properties for studs in the AWS D1.5 *Bridge Welding Code* vary from those in D1.1.

Specifying the Ferrule

The ceramic ferrule is needed to properly weld all drawn arc weld studs—the exception being very small-diameter studs and studs with very fast weld times (referred to as short-cycle studs). The ferrule serves two purposes: It acts like a crucible to hold the

molten metal around the base of the stud during the welding and cooling process, and it shields the molten metal from contamination by air, which can adversely affect the weld. Ferrules come in many different shapes and sizes, each specifically designed for the many different stud welding applications possible.

The most common ferrule, called a flat ferrule, is used when the stud is welded perpendicular to a flat horizontal surface below the stud (this is known as the down-hand position). Flat ferrules are also used for overhead stud applications, such as hanger systems. For vertical applications (where welding studs are positioned horizontally to a vertical surface) a special vertical ferrule with closed vents along the bottom of the ferrule is used for studs that are larger than 1/2 in. in diameter. Another common special ferrule application is for studs welded through metal decking materials to a supporting steel structure. This is called through-deck stud welding and requires a special “through-deck” ferrule; these ferrules have larger vent openings to allow the zinc plating and other contaminants on the decking material to escape from the weld zone. If



b) Shear connector fixed through profiled sheeting



- ▲ It is important to take into account the nominal melt-off length to determine the required stud length for the application.

the welding application involves welding in something other than down-hand position—such as into the toe or onto the heel of an angle—it is important to discuss this with your stud supplier to determine the right type of ferrule, as well as other stud welding parameters, for your needs. Ferrules are commonly provided free of charge with the purchase of the studs. If you have a specific application or need additional ferrules, it is important to indicate this during the ordering process.

Any job involving weld studs should start with specifying the correct stud and purchasing the proper ferrules for the intended application. Remember to gather the following information:

- ▶ required stud type
- ▶ base diameter of the stud
- ▶ required after-weld length
(and corresponding before-weld length)
- ▶ required material type
- ▶ purpose of the studs
- ▶ intended welding process
- ▶ welding conditions affecting the consumables (such as through-deck or out-of-position)

Proper specification and due diligence in the specifying states will lead to a faster, more efficient and more economical weld stud project. ■