steelwise

FROM MATERIALS TO PRODUCTS

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This month's SteelWise features answers to general questions on structural steel fabrication.

AISC IS UPDATING the Frequently Asked Questions section of its website (**www.aisc.org**). As these updates are created, selected sections will be published as SteelWise articles. This month's installment covers general fabrication questions.

2. General Fabrication

The AISC *Specification for Structural Steel Buildings* and *Code of Standard Practice for Steel Buildings and Bridges* cover the requirements for fabrication of structural steel. The FAQs in this section include a discussion of portions of these provisions and subsequent recommendations.

2.1. Material Identification and Traceability

2.1.1. What is required for the identification of material?

Identification means the ability to determine that the specified material grade and size are being used. Section 6.1 of the *Code of Standard Practice* states: "The *fabricator* shall be able to demonstrate by written procedure and actual practice a method of material identification, visible up to the point of assembling members." The *Code* goes on to describe in further detail the requirements.

2.1.2. What is the difference between traceability and identification of material?

Traceability means the ability to identify a specific piece of steel in a structure, throughout the life of the structure, and its specific mill test report (MTR). As such, traceability requirements are significantly more expensive than the identification requirements discussed in 2.1.1. The owner should clearly understand the differences, limitations and relative costs involved.

Traceability is not a requirement in the AISC *Specification* but, when required, must be clearly specified in the contract documents prior to the ordering of material. The following elements of traceability should be selected only as needed:

1. Lot traceability vs. piece-mark traceability vs. piece traceability: Lot traceability means that the materials used in a given project can be traced to the set of MTRs for that project. Piece-mark traceability means that the heat number can be correlated for each piece mark, of which there can be many individual pieces. Piece traceability means that the heat number can be correlated for each piece, which effectively demands separate piece marks for each piece. Each of these three successive levels of traceability adds significant costs. Piece traceability, the most expensive option, is necessary only in critical applications, such as the construction of a nuclear power facility. Piece-mark traceability is often specified for main members in bridges. Lot identification is most common in other applications where traceability is required.
2. Main-material traceability vs. all-material traceability: Main-material traceability means that beams, columns, braces and other main structural members are traced as specified above. All-material traceability means that connection and detail materials are also traced as specified above. All-material traceability, the more expensive option, is necessary only in critical applications, such as the construction of a nuclear power facility. In other cases, main-material traceability is sufficient when traceability is a requirement.
3. Consumables traceability means that lot numbers for consumables such as bolts, welding electrodes and paint can be traced. This is necessary only in critical applications, such as the construction of a nuclear power facility.
4. Required record retention defines the level of detail required in documenting traceability (who, what, when, where, how, etc.).
5. Fool-proof record retention vs. fraud-proof record retention: Fool-proof record retention means internal verification of records. Fraud-proof record retention means external certification of records. Fraud-proof record retention is necessary only in critical applications, such as the construction of a nuclear power facility. In other cases, fool-proof record retention is sufficient when traceability is a requirement.

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2.1.3. How does a fabricator maintain traceability when it is required?

Each heat of steel produced by the mill is tested for chemical content and mechanical properties, and the results are recorded on a MTR, which is provided to and maintained in the records of the fabricator. Each piece that is rolled from this heat is then labeled with an identification mark that relates to the corresponding MTR. The fabricator applies an identification mark to each piece. Because this piece mark remains with the piece throughout the fabrication and erection process, the material is traceable back to the MTR for that individual piece.

Many connecting elements and similar fittings are too small to accommodate the marks to identify the piece from which they were cut. Additionally, such items are commonly made from stock materials with marks that may have inadvertently been abraded or lost during years of storage. In such cases, the fabricator provides written certification that the stock material meets the contract requirements.

Manufacturers of consumables such as bolts, welding electrodes and paint provide documentation as to the content and specification compliance of their products. This documentation is provided to and maintained in the records of the fabricator. The packaging in which the products are shipped is referenced to this documentation.

In some cases, the fabricator may purchase materials through a steel service center. When this is the case, the steel service center must transmit the necessary documentation from the manufacturer to the fabricator.

2.2. Cutting and Finishing Steel

2.2.1. What methods are available for cutting steel, and what is the corresponding range of utility for each method?

The following methods are commonly used to cut steel:

1. Friction sawing, which is performed with a high-speed rotary blade, is commonly used by steel producers and is limited only by machine size. This cutting method, however, is no longer commonly used in fabrication shops.
2. Cold sawing, whether by rotary saw, hack saw or band saw, is limited only by machine size.
3. Oxygen-acetylene (and related fuel) flame cutting, which can be mechanically or hand-guided, is commonly used for general cutting and edge preparation operations, such as coping, beveling, notching, etc.; its utility is virtually unlimited.
4. Plasma cutting, which is mechanically guided, is generally useful for cutting plate up to 1 in. thick.
5. Laser cutting, which is mechanically guided, is generally useful for cutting plate; thickness limitations vary.
6. Shearing, which is performed with mechanical presses, is generally useful for cutting plates and angles and is limited only by machine size and capacity.

Additional minor material removal and finishing may also be accomplished by one of the methods listed in 2.2.2

2.2.2. What methods are commonly used to provide finished surfaces, when required?

Some of the cutting methods in 2.2.1 result in surfaces that are finished without further treatment; see 2.2.3 and 2.2.4. When this is not the case, the following methods are commonly used to provide finished surfaces:

1. Milling, which is commonly used to bring members to their required length and end finish.
2. Face machining, which can be used to finish large areas to exact dimensions.
3. Planing.
4. Grinding, which is commonly used for edge preparation, including treatment of flame-cut edges, removal of burrs, etc., when required.

2.2.3. Can the end of a column, as received from the rolling mill, be considered to be a finished surface?

Yes, provided the mill cut is square to the column axes and meets the surface roughness requirements in ASME B46.1 (see 2.2.6).

2.2.4. Is it commonly necessary to mill bearing surfaces after sawing?

No. As stated in the AISC *Specification* Section M2.6, "Compression joints that depend on contact bearing ... shall have the bearing surfaces of individually fabricated pieces prepared by milling, sawing or other suitable means." The AISC *Code of Standard Practice* Section 6.2.2 Commentary states that "most cutting processes, including friction sawing and cold sawing, and milling processes meet a surface roughness limitation of 500 in. per AISI/ASME B46.1." Cold-sawing equipment produces cuts that are more than satisfactory.

2.2.5. What constitutes acceptable thermal cutting practice?

Structural steel preferably should be thermally cut by mechanically guided means. However, mechanically guided cutting may not be feasible in some cases, such as the cutting of copes, blocks, holes other than bolt holes (see 2.4.1 and 2.4.2) and similar cuts. Accordingly, hand-guided thermal cutting should be allowed as an alternative. Regardless, thermally cut surfaces must meet the appropriate roughness limitations as summarized in 2.2.6.

2.2.6. What are the appropriate roughness limitations for thermally cut edges?

Inadvertent notches or gouges of varying magnitude may occur in thermally cut edges, depending upon the cleanliness of the material surface, the adjustment and manipulation of the cutting head and various other factors. When thermally cut edges are prepared for the deposition of weld metal, the AISC *Specification* Section M2.2 provides acceptance criteria that consider the effect of discontinuities that are generally parallel to the applied stress on the soundness of welded joints. Additionally, correction methods for defects of various magnitudes are stipulated therein. When thermally cut edges are to remain unwelded, the following surface condition guidelines are recommended:

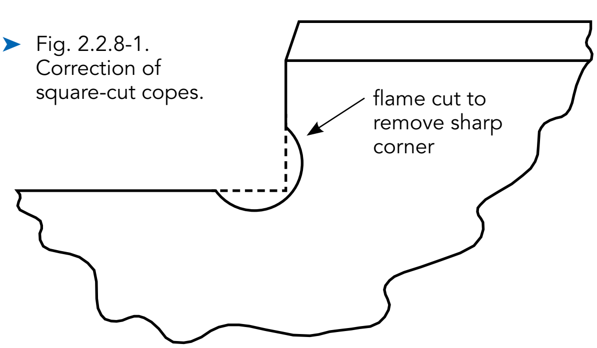
1. If subjected to a calculated tensile stress parallel to the edge, edges should, in general, have a surface roughness value not greater than 1,000 in. as defined in ASME B46.1.
2. Mechanically guided thermally cut edges not subjected to a calculated tensile stress should have a surface roughness value not greater than 2,000 in. as defined in ASME B46.1.
3. Hand-guided thermally cut edges not subjected to a calculated tensile stress should have a roughness not greater than 1⁄16 in.
4. All thermally cut edges should be free of notches (defined as a V-shaped indentation or hollow) and reasonably free of gouges (defined as a groove or cavity having a curved shape). Occasional gouges not more than 3⁄16 in. deep are permitted.

Gouges greater than 3⁄16 in. deep and all notches should be repaired as indicated in 2.2.7.

2.2.7. When surface roughness for thermally cut edges does not meet the limitations in 2.2.6, how is the surface repaired?

Roughness exceeding the criteria in 2.2.6 and notches not more than 3⁄16 in. deep should be removed by machining or grinding and fairing-in at a slope not to exceed 1:10. The repair of notches or gouges greater than 3⁄16 in. deep by welding should be permitted. The following criteria are recommended:

1. The discontinuity should be suitably prepared for good welding.
2. Low-hydrogen electrodes not exceeding 5⁄32 in. in diameter should be used.
3. Other applicable welding requirements of AWS D1.1 should be observed.
4. The repair should be made flush with the adjacent surface with good workmanship.
5. The repair should be inspected to assure soundness.



➤ Fig. 2.2.8-1. Correction of square-cut copes.

2.2.8. To what profile must reentrant corners, such as corners of beam copes, be shaped?

Reentrant corners should provide a smooth transition between adjacent surfaces, but generally need not be cut exactly to a circular profile. The recommendation in Part 9 of the AISC *Manual* is that an approximate minimum radius of ½ in. is acceptable. However, the primary emphasis should be that square-cut corners and corners with significantly smaller radii do not provide the smooth transition that is required. It is acceptable to provide radius transitions by drilling (or hole sawing) with common-diameter drill sizes (not less than ¾ in.).

When the corner of a cope has been square-cut, a common solution is to flame-cut additional material at the corner to provide a smooth transition as illustrated in Figure 2.2.8-1. Note that the sides of the cope need not meet the radius transition tangentially. Any notches that occur at reentrant corners should be repaired as indicated in 2.2.7.

2.3. Use of Heat in Fabrication

2.3.1. Is it permissible to use controlled heat to straighten, curve or camber structural steel shapes?

Yes. AWS D1.1Section 5.26.2 permits heat-straightening of members that are distorted by welding and stipulates rules for this procedure. These rules are equally applicable for all heat straightening or curving. Furthermore, the AISC *Specification* Section M2.1 and a discussion in the AISC *Manual* (Part 2), provide a sound basis for the use of controlled heat to straighten, curve, camber and form structural steel. The proper control of heat application generally involves the use of rosebud tips on torches to disperse the applied flame and temperature indicating crayons or similar devices to monitor the induced temperature.

2.3.2. Is it permissible to accelerate cooling of structural steel after the application of controlled heat?

Yes, however for cyclically loaded structures, the steel must first be allowed to cool ambiently to 600 °F. Because the maximum temperature permitted by the AISC *Specification* Section M2.1 for heating operations is below any critical metallurgical temperature for the material being heated, the use of compressed air, water mist or a combination thereof should be permitted to accelerate the final cooling. The limitation for cyclically loaded structures is more historical than technical in nature. As a fair balance between the needs of the fabricator and the concerns of the owner, it provides an added safeguard to prevent the abuse of excessive cooling and undesirable residual stresses should accepted procedures not be strictly monitored.

2.3.3. What are some good resources on heat cambering or heat straightening?

There are several references that are useful with regards to heat cambering or heat straightening:

1. Pages 2-37–2-38 of the 14th Edition *Manual*
2. AISC *Specification* Section M2.1
3. AWS D1.1 Section 5.26.2
4. "*Cambering Steel Beams*" by David Ricker, AISC *Engineering Journal*, 4th Quarter 1989
5. "Heat Straightening of Steel: From Art to Science" by Richard Avent, 1988 AISC Conference Proceedings
6. "Heat-Straightening Repairs of Damaged Steel Bridges," Report No. FHWA-IF-99-004, U.S. Department of Transportation, Federal Highway Administration, October 1998
7. "Principles and Practice of Heat Straightening Repair" by Richard Avent, 2001 AISC Conference Proceedings

▲ Applicable welding requirements of AWS D1.1 should be observed.

▲ The maximum length of a fabricated assembly is primarily limited by shipping and erectability concerns, such as overall length and total weight.

2.4. Bolt Holes

2.4.1. What are the acceptable methods for making bolt holes?

Acceptable methods for making bolt holes include:

1. Punching
2. Sub-punching and reaming
3. Drilling
4. Hole sawing
5. Flame piercing and reaming
6. Thermal cutting, subject to surface quality requirements as discussed in 2.4.2
7. Water jet cutting

2.4.2. What variation in profile is generally acceptable for bolt holes?

The slightly conical hole that naturally results from punching operations is acceptable, as noted in Table 3.1 of the RCSC *Specification*. The width of slotted holes that are produced by flame-cutting, or a combination of punching or drilling and flame-cutting, should generally be not more than 1⁄32 in. greater than the nominal width except that gouges not more than 1⁄16 in. deep are permitted. Thermally cut holes subjected to fatigue are not addressed in Appendix 3 of the AISC *Specification*.

2.4.3. Must burrs be removed in bolted connections?

The RCSC *Specification* Section 3.4 states: "Burrs less than or equal to 1⁄16 in. in height are permitted to remain on faying surfaces of all joints. Burrs larger than 1⁄16 in. in height shall be removed or reduced to 1⁄16 in. or less from the faying surfaces of all joints."

2.4.4. Are there any special hole size requirements in members or bolts that are galvanized?

No. Holes for galvanized bolts or members are not permitted to be larger than those specified in Table 3.1 of the RCSC *Specification*.

2.5. Correction of Fabrication Errors

2.5.1. Must fabrication errors always be repaired?

No. Because the human element is involved in all phases of structural steel fabrication, material inadvertently may be cut to the wrong length, holes may be misplaced, parts may be located incorrectly or notches or gouges may occur. However, many such errors or deviations need not be altered or repaired and are acceptable without change or penalty to the structure or its end use. Furthermore, some repair work may be more detrimental than leaving the piece unrepaired. In general, the structural engineer of record (SER) should evaluate the deviation and whether it would be detrimental to the end use of the product.

In some cases, repair will be required and can usually be made so that the member will meet all performance criteria. Corrective measures to meet the requirements of shop drawings and specifications may generally be made by the fabricator during the normal course of fabrication, using qualified personnel and procedures that meet AISC and AWS specifications. Such action is considered to be a part of the fabricator's quality control program and should not require either notification of, or approval from, the owner or SER. However, in cases where major work is involved (cutting or removal of welded members from a welded assembly, modification of design, deviation from critical dimensions, etc.), the SER should be consulted and a plan of corrective action agreed upon.

2.5.2. What repair is appropriate for material that is cut too short?

When material is short of the minimum required length, welded splices or deposited weld metal—when applied with appropriate welding procedures and specified material—should be permitted. However, the approval of the SER is required in such cases.

There are several acceptable methods for making bolt holes.

Each heat of steel produced by the mill is tested for chemical content and mechanical properties, and the results are recorded on a mill test report.

When detail parts are placed in error, minor mislocations should be investigated to determine if relocation is necessary.

2.5.3. What repair is appropriate for mislocated bolt holes?

Generally, mislocated fastener holes are not detrimental to the strength of a member if the remaining effective net section is adequate for the loads. As such, they may be left open or filled with bolts. If required, mislocated holes can be structurally repaired in accordance with Clause 5.26.5 of AWS D1.1. Attention should be paid to the Commentary to Clause 5.26.5, as it describes a rather involved process that can be used for such repairs. The process involves considerable gouging and welding, and therefore considerable heat input. As with all repairs, the benefits of the repair should be carefully weighed against the potential problems that the repair itself could cause. Plug welding of mislocated holes is not an acceptable structural repair. If a bolt hole is mislocated by a small amount—say, less than a bolt diameter—it is often possible to adjust the connection material to accommodate the error.

2.5.4. What repair is required when a minor member mislocation occurs?

When detail parts are placed in error, minor mislocations should be investigated to determine if relocation is necessary. When relocation is necessary, such as when dimensions are critical, the error is major or the incorrectly placed part is visually unacceptable under an AESS requirement, the incorrectly placed part should be removed. For a welded detail, flame cutting, gouging, chipping, grinding or machining may be required. Care should be taken to avoid damage to the main material of the associated member. The surface of the main material should be ground smooth and repaired, if necessary, as indicated in 2.2.6 and 2.2.7.

2.5.5. What is "moderate reaming" as indicated in the 2010 AISC *Code of Standard Practice* Section 7.14?

During the course of erection, it occasionally becomes necessary to ream holes so fasteners can be installed without damage to the threads, resulting in a hole that is larger than normal or elongated. The hole types recognized by the AISC and RCSC *Specifications* are standard, oversized, short-slotted and long-slotted, with nominal dimensions as given in the AISC *Specification* Table J3.3. The AISC *Code of Standard Practice* Section 7.14 Commentary states: "The term 'moderate' refers to the amount of reaming, grinding, welding or cutting that must be done on the project as a whole, not the amount that is required at an individual location. It is not intended to address limitations on the amount of material that is removed by reaming at an individual bolt hole, for example, which is limited by the bolt-hole size and tolerance requirements in the AISC and RCSC *Specifications*." Note that reamed holes must meet the provisions for minimum spacing and minimum edge distance in AISC *Specification* Sections J3.3 and J3.4, respectively.

When more major misalignments occur, it is indicated in the AISC *Code of Standard Practice* Section 7.14 that they are "promptly reported to the [owner] and the fabricator by the erector, to enable the responsible entity to either correct the error or approve the most efficient and economical method of correction to be used by others."

2.6. Other General Information

2.6.1. What precautions are required when cold bending material with sheared or flame-cut edges?

When cold bending plates or performing other operations involving cold bending and a sheared or flame-cut edge, care must be taken to preclude the initiation of cracks at the edge. Minimum inside radii for cold bending plates of various steel grades are indicated in ASTM A6 Appendix X4. It is indicated in the corresponding text therein that the tabular values may have to be increased when bend lines are parallel to the direction of final rolling or longer than 36 in. Additionally, the *Manual* states: "Flame-cut edges of hardenable steels should be machined or softened by heat treatment. Nicks should be ground out and sharp corners should be rounded."

2.6.2. What are the common length limits on fabricated structural steel members?

The maximum length of a fabricated assembly is primarily limited by shipping and erectability concerns, such as overall length and total weight. However, because individual practices and capabilities vary, it is best to consult with the fabricator directly.

The common solution to a member length concern is a splice, which may be necessary and/or desirable for fabrication, shipping and/or erectability considerations. When approved by the SER, fabricator-initiated splices in members are acceptable.

2.6.3. Common steel items, such as steel deck and open-web steel joists, are not considered to be structural steel in the 2010 AISC *Code of Standard Practice*. Why?

Even though items such as steel deck and open-web steel joists may be provided by the structural steel fabricator, they are not considered to be structural steel because they are neither manufactured nor fabricated by the structural steel fabricator. As such they are listed in Section 2.2 of the AISC *Code of Standard Practice* as "other steel, iron or metal items." Items that are normally part of the fabricator's work are listed as structural steel items in Section 2.1. of the AISC *Code of Standard Practice*.

2.6.4. What are the maximum and minimum curved radii of HSS and W-shapes?

Limits on radii of curved shapes are essentially a function of the capabilities of the bender. AISC does limit the radius of bend for bent plates to prevent cracking during the bending process. Though similar limits would apply to any bent product, such deformations are not generally achievable in HSS. Guidelines for bending plates are found in ASTM A6-Appendix X4.

Cold-bending guidelines for shapes are also found in the AISC *Manual*. They are summarized below:

1. The minimum radius for camber induced by cold-bending in members up to a nominal depth of 30 in. is between 10 and 14 times the depth of the member. Deeper members may require a larger minimum radius.
2. Cold-bending may be used to provide sweep in members to practically any radius desired.
3. A minimum length of 25 ft is commonly practical due to manufacturing/fabrication equipment.

Bending by heat is also a possibility, but it should be noted that this procedure is generally much more expensive than cold-bending.

Note that providers for structural shape (including HSS) curving/bending often advertise their services in *Modern Steel*. A list of AISC Associate Member Bender-Rollers can be found at **http://bit.ly/1ABwTV5**. They would be the best ones to contact for determining minimum and maximum curved radii of shapes. ■