A look at materials and products that are not included in the AISC *Specification's* list of approved materials.

steelwise

UNLISTED MATERIALS – PART 1

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THE AISC *SPECIFICATION* approves the use of several materials—but what about materials that it doesn't include?

Generally, the *Specification for Structural Steel Buildings* (ANSI/AISC 360, available as a free download at www.aisc.org/specifications) does not prohibit the use of any material. The use of unlisted materials and products—those that are not included in the list of approved materials—is left to the discretion of the engineer and can be viewed as a substitution of an unlisted material for an approved material.

An article about material substitutions (called "Material Substitutions") appeared in the August 2011 issue (www.modernsteel.com) and much of the information provided then is still applicable today. However, material substitutions seem to be more common today than they were in 2011, and familiarity may breed complacency if not contempt. Some engineers may erroneously believe that all steels and steel products are created equal and that material substitutions can be made with little thought. With this in mind, a fresh look is in order.

In this first of a series of three articles on the topic, we'll discuss the reasons for the treatment of materials that have been adopted by AISC *Specification*. We'll also include a discussion about the evaluation of unlisted materials based on a list of factors provided in the Commentary to Section A3 of the *Specification*. Let's start by addressing some basic questions.

Why does the AISC *Specification* include a list of approved materials?

The *Specification* has existed under various titles and in somewhat different forms for nearly a hundred years. Thousands of engineers around the world turn to the *Specification* on a daily basis to aid them with their designs. The *Specification* is also commonly referenced by other standards and specifications, sometimes relative to applications well outside the intended scope of the AISC Committee on Specifications.

Given the ubiquity and prominence of the *Specification*, engineers sometimes incorrectly believe that it can be used to design all steel structures using any material that can conceivably be classified as steel. This is not the case.

As stated in its scope, "The *Specification* shall apply to the design, fabrication and erection of the structural steel system or systems with structural steel acting compositely with reinforced concrete, where the steel elements are defined in Section 2.1 of the AISC *Code of Standard Practice for Steel Buildings and Bridges* (ANSI/AISC 303)… This *Specification* sets forth criteria for the design, fabrication and erection of structural steel buildings and other structures, where other structures are defined as structures designed, fabricated and erected in a manner similar to buildings, with building-like vertical and lateral load-resisting elements."

It is interesting to note that the *Specification* does not even include a definition of steel as a material. Instead, the range of materials that can be used is defined by two factors: application and references to ASTM specifications.

The scope of the *Specification* is limited to building design and is further limited by the definition of structural steel provided in the *Code*, which also defines steel elements not based on the physical properties of the material from which they are made, but rather based on their intended use.

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Limits are set based on material properties through references to ASTM specifications. Section A3 of the *Specification* lists ASTM specifications that are approved for use under the *Specification*. As indicated in the Commentary, the materials listed "are commonly useful to structural engineers" and "have a history of satisfactory performance."

The scope of the *Specification* is limited to certain applications and certain materials because these are the applications and materials that were considered when the various provisions of the publication were written or evaluated during updates. The standards in Section A3 are those representing materials commonly used for typical applications in building-type structures. Most of them are available in the supply chain from producers and service centers that routinely participate in the U.S. structural steel industry. The plethora of specifications for materials suitable for other structure types, unusual applications or from other countries is immense. It is beyond the capability of AISC committees to maintain such a comprehensive list.

Why are other materials not prohibited?

The simple answer is provided in the Commentary: "Other materials may be suitable for specific applications." There is no reason in building design to limit materials when other materials may be suitable.

It also has to be recognized that the structural steel industry, despite its age, is still a vibrant and evolving industry. The Commentary to the 1963 *Specification* states: "The increasing use of high-strength steels no longer permits the continuation of a standard design specification based upon the exclusive use of one strength grade of steel." The 1963 version required that structural steel conform to one of six listed ASTM specifications. The 1969 edition doubled the number of listed steels, and for the first time stated that the listed materials were "approved for use under this *Specification*."

Sometimes materials are developed to serve specific purposes related to building design that might provide a significant benefit, but that have not yet been adopted by the *Specification*—because of the length of the code cycle or for other reasons. There is no good reason for the *Specification* to stand in the way of such innovation. History indicates that innovation generally starts with industry and engineering, and the *Specification* simply follows suit.

How should unlisted materials be evaluated?

The evaluation of unlisted materials is the responsibility of the engineer specifying or approving them. The Commentary provides a list of some (but certainly not all) of the considerations. These include:

- Typical strength properties – F_y and F_u
- Strength properties in transverse directions
- Ductility
- Formability
- Soundness
- Weldability, including sensitivity to thermal cycles
- Notch toughness
- Other forms of crack sensitivity
- Coatings
- Corrosivity
- Effects of production
- Tolerances
- Testing
- Reporting
- Surface profiles

Some of these items are discussed further in the below sections. This should not be viewed as a complete list of factors that must be considered, but it will provide a start.

Typical strength properties

When considering a proposed material substitution, perhaps the two most requested properties of the substituting material are the yield strength and the tensile strength, but one should remember that outwardly similar materials can behave very differently in ways that are not always apparent from the numerical values of F_y and F_u.

The way in which these values are determined can also determine whether apples are being compared to apples or to oranges. This is discussed further relative to testing.

Strength properties in transverse directions

Engineers often assume steel is homogeneous and isotropic, and this assumption is adequate for most designs using approved materials that are addressed in the *Specification*. However, steel is a manufactured material, and steel shapes and plates are manufactured products. The manufacturing process introduces and modifies inclusions in the steel. The manufacturing process for long products includes hot rolling, which elongates the grains in one direction and can also elongate inclusions. This results in different properties in the direction of rolling as compared to properties in the transverse direction or through thickness directions (anisotropy).

Lamellar tearing is one consideration related to this anisotropy. Several factors play a part in lamellar tearing, including joint configuration and steel chemistry. The manufacturing process itself also plays a role. The current steelmaking practice of continuous casting places demands on the producer that have the benefit of controlling the shape of inclusions and improving through-thickness strength. Therefore, current continuous cast products have less likelihood of lamellar tearing than did older ingot cast products. Engineers can reduce the likelihood of lamellar tearing through good design practice, as described in Design Guide 21: *Welded Connections—A Primer for Engineers* (www.aisc.org/dg). Material specifications define some aspects of chemical composition, such as limits on sulfur, which can be objectively evaluated assuming the proper expertise, but the details of the manufacturing process may be more difficult to know and to evaluate.

Ductility

Ductility is the ability of a material to deform plastically before fracturing. In many respects, it is the magic ingredient that makes structural design practical. Ductility can be measured or quantified in various ways. The *Specification* defines rotation capacity as "incremental angular rotation defined as the ratio of the inelastic rotation attained to the idealized elastic rotation at first yield prior to significant load shedding." The *Seismic Provisions for Structural Steel Buildings* (ANSI/AISC 341, available as a free download at www.aisc.org/specifications) quantifies ductility demand based on story drift or building drift. Such measures of ductility can include factors other than material properties.

Chapter K of the *Specification* uses the ratio of the specified minimum yield strength to the specified minimum tensile strength (yield/tensile ratio) as a measure of ductility. Ductility as it relates solely to material is usually defined in terms of elongation or reduction of area in tension tests, and minimum values are specified in ASTM standards.

Appendix 1 in the *Specification* directly addresses ductility when engineers implement design by inelastic analysis. A level of ductility consistent with the approved materials is assumed relative to the rest of the *Specification* as well. Ductility is required in all structures designed using the *Specification* because common design methods use approximation to calculate available and required strengths of elements that may not be justified if those elements are not sufficiently ductile to redistribute uneven stresses.

Formability

Formability is the ability of the steel to be plastically deformed without fracture. Formability is often not considered in design under the *Specification*, but it plays in role in such operations as cambering and cold bending of plates. Some standard shop practices may no longer be appropriate if the formability of the material specified differs from that of the materials approved for use in the *Specification*.

Increased inspection of cambered beams and bent plates may be appropriate until the formability limits of the specified material have been established.

Weldability

Not all steel can be effectively welded. The heat associated

with welding is detrimental to the properties of some steels, and some steel is inherently prone to weld-induced cracking. Weldability is a significant consideration when evaluating unlisted materials.

AWS D1.1, which is adopted by reference in the *Specification*, categorizes materials by groups, which are then used to establish things like base and filler metal combinations for prequalified welds. The range of materials addressed in AWS D1.1 is much larger than the approved materials in the *Specification*, but not all materials are addressed. Welding procedure specifications (WPS) for materials not listed in AWS D1.1 must be qualified. This process can be very time-consuming and expensive.

Chemical composition also has a significant effect on the weldability of steel. Design Guide 21 contains a good discussion of weld cracking, including the effect of steel chemistry.

Notch toughness

Toughness is the ability of a material to deform and absorb energy before fracturing. Though it is not always obvious many of the standard U.S. fabrication practices rely on a certain level of toughness. Experience has shown that the approved materials in the *Specification* have sufficient toughness for use in buildings using typical U.S. fabrication and design practices. Where toughness is more of a concern, such as for heavy shapes in certain applications, the *Specification* imposes explicit toughness requirements. The ability to leave backing in place, the lack of a defined radius for reentrant corners and the range of methods permitted to form bolt holes are all tied to toughness.

The Commentary to Section A3.1a states: "For especially demanding service conditions such as structures exposed to low temperatures, particularly those with impact loading, the specification of steels with superior notch toughness may be warranted. However, for most buildings, the steel is relatively warm, strain rates are essentially static and the stress intensity and number of cycles of full design stress are low. Accordingly, the probability of fracture in most building structures is low. Good workmanship and good design details incorporating joint geometry that avoids severe stress concentrations are generally the most effective means of providing fracture-resistant construction." This guidance is only applicable to steel similar to those approved for use with the *Specification*.

Special detailing, explicit consideration of fatigue and/or increased inspections in building applications might be necessary if steels with low toughness are to be used. ■

The discussion on evaluating unlisted materials will continue in Part 2 of this three-part series, which will appear in next month's issue.

Listed Consumables for Welding

- AWS A5.1
- AWS A5.5
- AWS A5.17
- AWS A5.18
- AWS A5.20
- AWS A5.23
- AWS A5.25
- AWS A5.26
- AWS A5.28
- AWS A5.29
- AWS A5.32
- AWS A5.36

Listed Fasters

Bolts:

- ASTM A307
- ASTM A354
- ASTM A449
- ASTM F3043
- ASTM F3111
- ASTM F3125

Nuts:

- ASTM A194
- ASTM A563
- ASTM A563M

Washers:

- ASTM F436
- ASTM F844

Compressible-Washer-Type DTIs:

- ASTM F959

Anchor Rods and Threaded Rods:

- ASTM A36
- ASTM A193
- ASTM A354
- ASTM A449
- ASTM A572
- ASTM A588
- ASTM F1554

Listed Plates and Shapes

Hot-rolled structural shapes:

- ASTM A36
- ASTM A572
- ASTM A709
- ASTM A992
- ASTM A529
- ASTM A588
- ASTM A913
- ASTM A1043

Hollow structural sections:

- ASTM A53 Grade B
- ASTM A847
- ASTM A1065
- ASTM A1085
- ASTM A500
- ASTM A501
- ASTM A618

Plates:

- ASTM A36
- ASTM A242
- ASTM A283
- ASTM A514
- ASTM A529
- ASTM A572
- ASTM A588
- ASTM A709
- ASTM A1043
- ASTM A1066

Bars:

- ASTM A36
- ASTM A529
- A572
- ASTM A709

Sheets:

- ASTM A606
- ASTM A1011 SS, HSLAS and HSLAS-F