# Mechanical Properties of Bridge Steels

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## 1.0 INTRODUCTION

Structural steels for use in bridges generally have more stringent performance requirements compared to steels used in buildings and many other structural applications. Bridge steels have to perform in an outdoor environment with relatively large temperature changes, are subjected to millions of cycles of live loading, and are often exposed to corrosive environments containing chlorides. Steels are required to meet strength and ductility requirements for all structural applications. However, bridge steels have to provide adequate service with respect to the additional Fatigue and Fracture limit state. They also have to provide enhanced atmospheric corrosion resistance in many applications where they are used without expensive protective coatings. For these reasons, structural steels for bridges are required to have fracture toughness and often corrosion resistance that exceed general structural requirements.

This course is written from a structural engineer's perspective and focuses on performance aspects of structural steel. A general overview of steel making practice is provided for information, stressing factors that may be relevant to the structural engineer and the structural performance of the product. The primary focus is on steel plate and rolled shape products that are available under the ASTM A 709 Specification. This includes both a general introduction to steel making practices and a detailed discussion of mechanical properties. It also includes a brief introduction to other steel products such as bolts, castings, cables, and stainless steels that are often used for steel bridge connections and components. References are provided to the relevant AASHTO and ASTM standards for additional information.

The mechanical properties of bridge steels are presented based on the A 709 specification. The stress-strain behavior of the various steel grades is presented to provide an understanding of strength and ductility. Fracture toughness is discussed to relate how the Charpy vee-notch test relates to fracture resistance in structures. Finally, the methodology for determining atmospheric corrosion resistance is presented along with the requirements for classification as "weathering steels" for use in un-coated applications.

## 2.0 PRODUCT SPECIFICATIONS

There are two organizations that publish standards for structural steel in the U.S. The American Society for Testing and Materials (ASTM) is a non-profit voluntary standards organization that develops consensus standards for steel products. Committee A-1 and subcommittee A01.02 have the primary responsibility for structural steel standards, including bridge steels (1). Membership is comprised of experts from industry, end users, government, and academia to provide a balance of perspectives. The American Association of State Highway Transportation Officials (AASHTO) publishes a separate volume of standards (2) that also include structural steel standards for bridge applications. These standards are developed by committees comprised solely of government officials responsible for construction and maintenance of the highway system. In most cases, the AASHTO standards are very similar or identical to the corresponding ASTM standards. This is particularly true for bridge steel products. The question arises, why do we need two identical standards? By keeping independent standards, AASHTO maintains the right to modify the ASTM requirements if it is determined to be in the public's interest.

Most bridge owners specify adherence to the AASHTO material specifications in their construction documents. Some specify ASTM specifications. In most cases, the two are identical for steel products. Table 1 shows the applicable AASHTO and ASTM standards for steel product categories. Some of the ASTM standards do not have an AASHTO counterpart. The following sections provide an overview of the specification provisions.

**Table 1 Cross reference between AASHTO and ASTM standards for bridge steel products.**

| Product | AASHTO Specifications | ASTM Specifications |
|---|---|---|
| Structural Steel for Bridges | M270/M270M | A709/A709M |
| Structural Stainless Steel | | A1010 |
| Cold-Formed Welded or Seamless Tubing | | A500 Grade B |
| Hot-Formed Welded or Seamless Tubing | | A501 |
| Pins, Rollers, and Rockers | M169<br>M102/M102M | A108<br>A668/A668M |
| Bolts | <br>M 164<br>M 253 | A307 Grade A or B<br>A325<br>A 490<br>F1852 |
| Galvanized Structural Bolts | M 232/M 232M Class C<br>M 298 Class 50 | A153/A153M<br>B695 |
| Anchor Bolts | M314-90 | A307 Grade C<br>F1554 |
| Nuts | M291 | A563 |
| Washers | M293 | F 436<br>F 959 |
| Shear Studs | M169 | A108 |
| Cast Steel | M 103/M103M<br>M 163/M163M | A27/A27M<br>A743/A743M |
| Ductile Iron | | A536 |
| Malleable Castings | | A47 Grade 35018 |
| Cast Iron | M105 Class 30 | A48 Class 30 |
| Stainless Steel | | A 176<br>A 240<br>A 276<br>A 666 |
| Cables | | A510 |
| Galvanized Wire | | A641 |
| Epoxy Coated Wire | | A99 |
| Bridge Strand/<br>Bridge Rope | | A 586<br>A 603 |
| Wire Rope | M277 | |
| Seven-Wire Strand | M203/M203M | A416/A416M |
| High Strength Steel Bar | M275/M275M | A722/A722M |

## 2.1 Structural Plate and Rolled Shapes

The ASTM A 709 Standard Specification for Structural Steel for Bridges (3) was established in 1974 as a separate specification covering all structural grades approved for use in main members of bridge structures. Many of the A 709 provisions are identical to those in the individual structural steel specifications applicable for more general use. Table 2 provides an overview of the various steel grades covered by the specification. The number in the grade designation indicates the nominal yield strength in ksi. The A 709M specification is the metric version of A 709.

**Table 2 Overview of bridge steels available in the A 709 specification.**

| M 270 A 709 GRADE | ASTM Specification | Description | Atmospheric Corrosion Resistance | Product Categories | | | |
|---|---|---|---|---|---|---|---|
| | | | | Plates | Shapes | Bars | Sheet Piles |
| 36 | A 36 | Carbon Steel | No | X | X | X | |
| 50 | A 572 | HSLA Steel | No | X | X | X | X |
| 50S | A 992 | Structural Steel | No | | X | | |
| 50W | A 588 | HSLA Steel | Yes | X | X | X | |
| HPS 50W | A 709 | HSLA Steel(*) | Yes | X | | | |
| HPS 70W | A 709 | Heat Treated(*) HSLA Steel | Yes | X | | | |
| HPS 100W | A 709 | Q&T Cu-Ni Steel(*) | Yes | X | | | |

(*) High Performance Steel (HPS) grades with enhanced weldability and toughness
HSLA High Strength Low-Alloy
Q&T Cu-Ni Quenched & Tempered Copper-Nickel Steel

### 2.1.1 Grade 36

The ASTM A 36 specification was originally adopted in 1960 as the final evolution of weldable carbon-manganese structural steel. Of all the steels in the A 709 specification, this is the easiest and cheapest to produce in steel mills that produce steel by melting iron ore in a blast furnace. Much of the steel making practice in the U.S. has now switched to electric furnace production where a large percentage of scrap is used to produce structural steel. Since scrap typically has more alloy elements than required by the A 36 specification, the resulting steel strength is typically much higher. The steels being delivered today as Grade 36 typically have strengths closer to 50 ksi than 36 ksi.

### 2.1.2 Grade 50

Grade 50 is the most common grade of structural steel available today. The A 572 specification was originally adopted in 1966 to introduce this higher strength grade of weldable structural steel. The strength was obtained by adding small amounts of columbium, vanadium, and sometimes titanium to the basic carbon-manganese chemistry of A 36 steel. This resulted in a 39% increase in yield strength compared to A 36 steel. The resulting increase in structural efficiency provided by the higher strength more than offset the increased cost of adding alloy to the steel. Grade 50 rapidly became the material of choice for primary bridge members that are to be painted or galvanized in service.

### 2.1.3 Grade 50W

Grade 50W is a special version of 50 ksi steel that was developed to have enhanced atmospheric corrosion resistance. This is commonly called "weathering" steel and is capable of performing well without paint or other coatings in many bridge applications. Different steel companies initially developed competing proprietary grades that were included in the A 588 specification in 1968. The added corrosion resistance was achieved by adding different combinations of copper, chromium, and nickel to the grade 50 chemistry to provide enhanced corrosion resistance. There is an added cost for grade 50W compared to grade 50, but this cost is often offset by the savings realized by eliminating the need to paint bridge structures.

### 2.1.4 Grade 50S

The A 992 specification was introduced in 1998 to keep pace with changes in rolled shape production practices in the U.S. As was previously discussed for Grade 36, the shift to scrap- based production made Grade 36 materials somewhat obsolete. Steels under the A 992 specification are dual certified to qualify for Grade 36 or Grade 50. It is more difficult to precisely control the chemical composition of scrap-based steel production since many alloys may be present in scrap steel. Therefore, the A 992 specification allows a wide range of steel chemistry. However, too much alloying can adversely affect the performance of structural steel and maximum percentages are set for C, Si, V, Co, P, S, Cu, Ni, Cr, and Mo. As long as the alloying stays below these maximum levels, the specification is largely performance-based upon meeting the required strength and ductility requirements.

### 2.1.5 Grade 100 and 100W

A 514 steel is a high strength (100 ksi), quenched and tempered product that was originally introduced in 1964. The specification has different grades with different chemical composition requirements corresponding to products from different steel producers. All grades have the same mechanical property requirements and can be considered equivalent for structural applications.

While the A 514 steels are weldable and are included in the D1.5 Bridge Welding Code, there have been a number of reported problems in fabrication. In some cases, delayed hydrogen cracking has been discovered both in the fabrication plant and through in-service inspection of bridges. The history of weldability problems for this grade was one of the catalysts for development of the new HPS grades discussed in the following section. In 2010, the A 709 Specification was revised to delete grades 100 and 100W. HPS 100W is now the only grade permitted for structural bridge members.

Engineers may still specify A 514 Grades 100 and 100W for bearing components and other secondary components in bridges. Since A 514 steels are used in other industries, there may be better availability in small quantities.

### 2.1.6 HPS Grades

The high performance steel (HPS) grades were developed through a cooperative agreement between the Federal Highway Administration, the U.S. Navy, and the American Iron and Steel Institute. The goal was to enhance weldability and toughness compared to previous versions of grade 70 and 100 steel (4). Prior to HPS, steels with yield strength greater than 50 ksi (A 852 and A 514) were very sensitive to welding conditions and fabricators often encountered welding problems. The HPS grades have essentially eliminated base metal weldability concerns. In addition, HPS grades provide enhanced fracture toughness compared to non-HPS grades. Because of the greatly enhanced properties, the original grade 70W steel (A 852) has been

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