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# High Performance Steel For Highway Bridges

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# HIGH PERFORMANCE STEEL FOR HIGHWAY BRIDGES

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## ABSTRACT

All steels possess a combination of properties that determines how well steel performs. Strength, weldability, toughness, ductility, corrosion resistance, and formability are all important to determine how well steel performs. High-performance steel (HPS) can be defined as having an optimized balance of these properties to give maximum performance in bridge structures while remaining cost-effective.

## 1. INTRODUCTION

The U.S. Transportation system represents huge investments on the part of governments and taxpayers. There is a widespread concern over the state of infrastructure. Despite indications of increased investment, it is clear that funds available are not likely to meet all of the needs of this sector in the long run. More than ever, wise investment decisions concerning roads and bridges will be crucial to the future of transportation.

The problem we face today, such as the aging infrastructure, stretches our resources thin and challenges our creativity. As a critical part of the infrastructure, deficient bridges represent a major impediment to mobility on our highways. The resultant time lost to congestion is a drag on our nation's productivity. Innovative materials, such as high performance steel, will play an increasingly important role as we attempt to meet all of the transportation challenges of the future, including enhancing and expanding our bridge infrastructure. We will be more dependent on high performance materials such as High Performance Steel to give us structures that have 100-year design lives *and that will help us with our goal to improve mobility by eliminating deficient bridges.*

## 2. DEVELOPMENT OF HIGH PERFORMANCE STEEL

Two new grades of high-performance structural steel, HPS-70W and HPS-50W, are developed and now commercially available for highway bridge construction. Experiences on the HPS demonstration projects are very promising, and it should have a significant impact on the bridge industry. This research and development effort has been a model partnership between government, industry, and academia to improve cost-effectiveness of highway bridge construction. FHWA, U.S. Navy, AISI, various universities, and state DOTs have played key roles in this program. Results are being touted as "the fastest ever technology transfer within the bridge construction industry in North America." The payoff from this research should be quickly realized through cost savings, and more durable and reliable bridges.

## 3. WHAT IS HIGH PERFORMANCE STEEL?

All steels possess a combination of properties that determines how well a steel performs its intended function. Strength, weldability, toughness, ductility, corrosion resistance, and formability are all important to determine how well a steel performs. High-performance steel can be defined as having an optimized balance of these properties to give maximum performance in bridge structures while remaining cost-effective.

- High Performance Steel has low levels of carbon and carbon equivalents to provide good weldability. It is weldable with reduced or no preheat and without expensive welding techniques.
- It has a high level of fracture toughness (Zone 3 minimum) to improve structure reliability. It provides better than adequate material ductility.
- It has atmospheric corrosion resistance characteristics that will eliminate the need for coating steel bridges in most environments.

## 4. MATERIAL PROPERTIES OF HPS

Table 1 - Chemistry for Convention and High Performance Steels

| | | C | Mn | P | S | Si | Cu | Ni | Cr | Mo | V |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Old 70W * | Min. | - | .80 | - | - | .25 | .20 | - | .4 | - | .02 |
| | Max. | .19 | 1.35 | .035 | .04 | .65 | .40 | .50 | .70 | - | .10 |
| HPS 70W & HPS 50W | Min. | - | 1.10 | - | - | .30 | .25 | .25 | .45 | .02 | .04 |
| | Max. | .11 | 1.35 | .020 | .006 | .50 | .40 | .40 | .70 | .08 | .08 |

* The conventional ASTM and AASHTO 70W grade steel has been replaced by HPS 70W grade steel.

Table 2 - Mechanical Properties for High Performance Steel Plates

| | HPS 50W<br>Up to 3" As-Rolled | HPS 70W<br>Up 4" (Q&T). 2" (TMCP) |
|---|---|---|
| Yield Strength, Fy, ksi (MPa) min. | 50 (345) | 70 (485) |
| Ultimate Tensile Strength, Fu ksi (MPa) | 70 (485) | 85-110 (586-760) |
| CVN at -10°F (-23°C) AASHTO minimum** required | 30 ft.-lbs. (41 J) | 35 ft.-lbs. (48 J) |

**CVN tests show that HPS has CVN toughness far exceeding the minimum AASHTO required.

## 5. WEATHERING CHARACTERISTIC OF HPS

It was part of the initial research objective to develop HPS with "weathering characteristic", meaning HPS should have the ability to perform without painting under normal atmospheric conditions. HPS has slightly better atmospheric corrosion resistance than the conventional grade 50W or 70W steels. For example, as measured in accordance with ASTM G101, the atmospheric corrosion resistance index (CI) for conventional Grade 70W is 6.0, while the index for HPS 70W is 6.5.

## 6. WEDABILITY OF HPS

Weldability is a property that is somewhat difficult to define. During welding, the conventional 70 ksi steels typically require preheating of plates, control of temperature of weld passes, controlled handling of welding consumables, precisely controlled energy input, and post-weld heat treatment in some cases. When all of these operations are performed correctly, it is usually possible to produce high-quality welds in conventional high-strength steel. However, these steels are much more difficult to weld and much less forgiving to variations in welding practice than the lower-strength steels. The reason for this is that higher strength levels usually are achieved by increasing content of carbon and alloying elements in steel. Unfortunately, weldability is inversely proportional to carbon content and the amount of alloying elements. High carbon content of current conventional steels, needed to achieve high strength, leads to cracking during construction or while in service. To reduce cracking problems from welding, these steels require pre- and post-heating during welding. These procedures lead to increased fabrication cost. The goal in developing HPS grades is to provide a steel that is forgiving enough to be welded under a variety of conditions without requiring excessive weld-process control that increases cost.

Although High Performance Steels have the same strength levels as the currently available high strength steels, their unique chemical and physical properties facilitate economical fabrication practices. Strength of HPS comes from heat treatment process rather than from carbon. Carbon content of HPS is very low, therefore, it has good weldability and does not require expensive preheat or other special welding considerations, required for conventional steel, during welding. One of the goals in developing high performance steel is to reduce or eliminate preheat. This goal has been successfully accomplished as shown in Table 3 below.

Table 3 - Minimum Preheat

| | Diffusible Hydrogen | | |
|---|---|---|---|
| | H4* | H8* | H16* |
| AASHTO M270 Grade 70W | 212°F (100°C) | 248°F (120°C) | 248°F (120°C) |
| HPS 70W | 70°F (21°C) | 100°F (38°C) | 150°F (66°C) |

* Denotes the level of hydrogen measured in the laboratory in terms of milliliter per 100 grams of deposited weld metal, e.g. H4 means 4 ml/100g of diffusible hydrogen in the weld metal.

## 7. FRACTURE RESISTANCE OF HPS

High Performance Steel has much higher fracture toughness than the conventional grades of steel used for bridge construction. Figure 1 shows the Charpy V-Notch (CVN) transition curves for HPS 70W and conventional AASHTO M270 Grade 50W steel. The brittle-ductile transition of HPS occurs at a much lower temperature than conventional Grade 50W steel. This means that HPS 70W(485W) remains fully ductile at lower temperatures where conventional Grade 50W steel begins to show brittle behavior. This has the beneficial effect of eliminating sudden brittle failure. As a result, reliability is enhanced as the net section can be relied on to resist applied forces should any crack develop in a structure.

With higher fracture toughness, HPS has much higher crack tolerance than conventional grade steels. Tolerance of cracks can offer several performance benefits for HPS bridges. Greater crack tolerance increases the available time window for detecting and repairing fatigue cracks before the structure might become unsafe. The net section yield criteria provide an easy way for engineers to assess the significance of cracks once they are found.

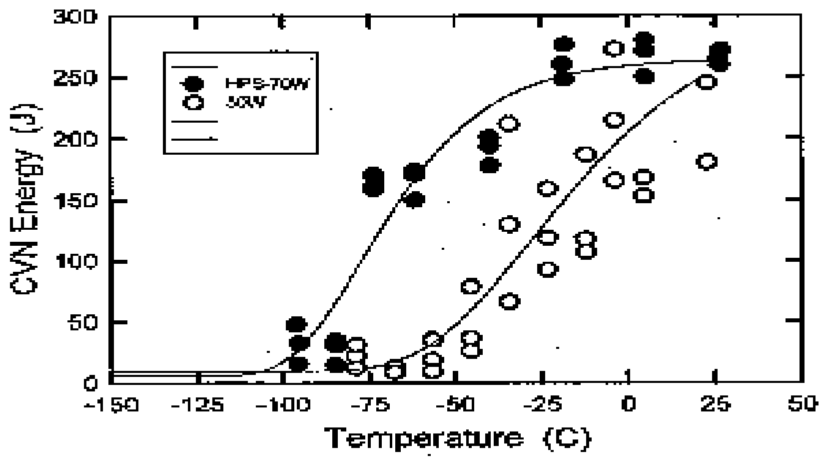


**Figure 1: CVN Transition Curve**

## 8. STEEL SPECIFICATIONS

High performance Steel is a quenched and tempered plate product available in thickness to 4 inches for use in bridges. It conforms to ASTM A709/A709M-01 specification requirements. It is also a Thermo-Mechanical-Controlled-Processed (TMCP) (Non-Q&T) product and is available in thickness to 2 inches for use in bridges.

## 9. AS DELIVERED BASE METAL

Owners, Designers and Fabricators must be aware that the length of HPS70W and HPS50W Quenched and Tempered (Q&T) steel plates is limited to 50 feet maximum as a result of the heat-treating process, regardless of the manufacturer. Use of Q&T material may result in introduction of additional weld splices in girder webs and flanges. The goal is to eliminate the need for quenching and tempering in production process. Once this is achieved, the plate length limitation of about 50 ft. will be eliminated. Currently, HPS70W (Thermo-Mechanical-Controlled-Processing) TMCP plates are available in thickness to 2 inches, with widths and lengths similar to that of Grade 50W steel plates.

## 10. FATIGUE PRONE DETAILS

The fatigue resistance of high performance steels is controlled by fatigue-prone details. Tests of welded high performance steel connections conclude that the fatigue categories given in LRFD, Section 6.6.1 also apply to high performance steels. The effective use of high performance steels can be improved by avoiding fatigue-prone details.

Among the characteristics most likely to improve the fatigue resistance of high-performance steel is the enhanced reliability due to ease of fabrication. Cracking of the base metal due to hydrogen is largely eliminated. The ability to weld with reduced or no preheat improves the working environment so that more reliable welds are produced.

## 11. THE GUIDE FOR HIGHWAY BRIDGE FABRICATION WITH HPS70W STEEL

A significant effort has been made to define welding guidelines for HPS70W. As a result of this effort a “Guide for Highway Bridge Fabrication with HPS70W Steel” has been developed. It is adopted by AASHTO and available as an AASHTO Guide. The guide has been prepared as a supplement to the AWS D1.5-95 Bridge Welding Code. The guide has been developed to ensure proper use of the new product. It has been developed with assistance of FHWA, AISI, AISC, steel companies, welding consumable companies, State DOTs and academia. Weldability is the primary focus of the fabrication guide.

The Guide includes sections discussing fabrication experiences, techniques, repairs, cost-effective HPS designs, and future actions and research.

- Appendix ‘A’ of the Guide contains Special Provisions for Fabrication with HPS-70W steel.
- Owners can either incorporate this Appendix ‘A’ directly in contract documents or use it as a guide in developing contract document language regarding use of this material.

The Guide effectively addresses those issues that are required to fabricate this material successfully, and with freedom from hydrogen-related cracking. While HPS70W has greater resistance to Heat Affected Zone (HAZ) cracking, currently available matching strength weld metals are subjected to hydrogen-assisted cracking. Such cracking requires specific fabrication practices. Under matching weld metal offers several advantages and is encouraged for fillet welds. Use of matching weld consumable is recommended for full penetration Groove welds.

## 12. FABRICATION EXPERIENCE

Fabrication of girders with High Performance Steel may require some modification to standard shop practices.

### 12.1 Drilling and Reaming

Initially, drilling and reaming was extremely difficult. Drill bits and reamers dulled quickly, until it was learned that when the holes are flooded with lubricants, HPS70W steel is no more difficult to drill or ream than conventional Grade 50W steels.

### 12.2 Mill Scale Removal

Mill scale removal from HPS70W steel by abrasive blasting basically requires the same work effort as that for Grade 50W. However, mill scale removal by grinder has been reported to be extremely difficult for quenched and tempered steel. There have been no reports of difficult mill scale removal for the TMCP product.

## 13. COST EFFECTIVE DESIGN

### 13.1 High Performance Bridges

The ultimate goal of the development of HPS steels is to provide owners “High Performance Bridges”. Since portions of any steel bridge will not require 70 ksi strength levels to satisfy capacity needs, lower strength steel can be used. Additionally, serviceability limitations, may dictate that a lower strength steel would be appropriate. HPS50W is now available in the market. Combining this improved version of 50W with other high performance materials for decks and substructures, will provide owners a truly “High Performance Bridge”.

### 13.2 Hybrid Girder Design

The use of hybrid girders, that is, girders using different grades of steel in the same cross section, as required to achieve design strength, appears to offer the most economical use of high performance steel. As an example, the most economical hybrid combination could be grade 50W for all webs and positive moment top flanges, with grade HPS70W for negative moment top flanges and all bottom flanges, and with Grade 50W welded attachments, such as, bearing stiffeners, connection plates, web stiffeners, etc. Generally, the cost of HPS base metal is inherently more than Grade 50W as a result of heat-treating processes. A hybrid girder provides for additional strength and/or toughness where required by design, and uses the lesser strength materials at other locations consistent with design requirements.

### 13.2 Other Design Considerations

Since the length of quenched and tempered plates is restricted to 50 feet, designers should select plate lengths and field splice locations that will minimize the number of butt shop splices, consistent with design requirements. Further, the use of HPS TMCP product is recommended wherever thickness permits. Further economy can be realized by limiting fillet welds to single pass, 1/4" or 5/16" welds consistent with the AWS D1.5 *Bridge Welding Code*, unless required by design loads.

In addition to reduced fabrication costs, additional savings can be realized with High Performance Steel due to reduce transportation costs, reduced structure depth, reduction in fill heights, reduced maintenance costs and reduced foundation costs.

## 14. EXPERIENCE OF STATE DOTS

The State DOTs are very pleased and are completely satisfied with the HPS bridges constructed to date. The HPS will now be routinely used in all their future projects, where they are appropriate.

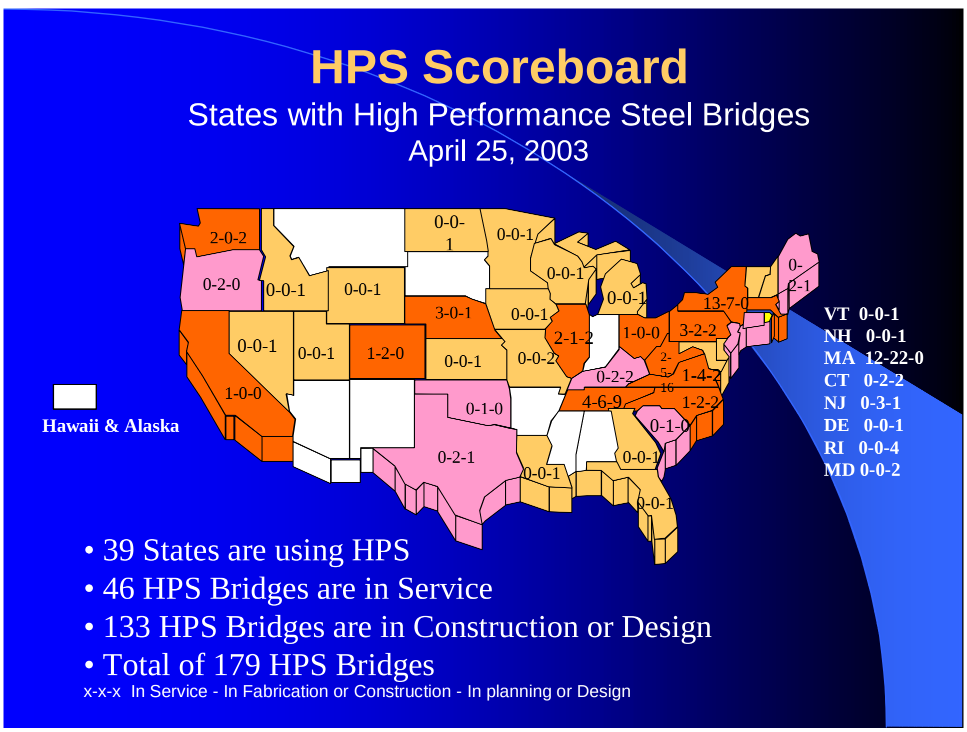


**Figure 2: States with HPS Bridges**

This figure shows the states, which have HPS bridges in service, in construction and/or in design. The orange color represents States with HPS bridges in service. The pink color represents States with HPS bridges in construction and/or Fabrication. The yellow color represents States with HPS bridges in planning or design. The three numbers (i.e. 1-3-2), indicate the number of HPS Bridges in Service – HPS Bridges in Construction - HPS Bridges in Design.

- 39 States are using HPS
- 46 HPS Bridges are in service
- 133 HPS Bridges are in construction or design.
- Total of 179 HPS bridges are in US.

## 15. SUMMARY

### 15.1 HPS is cost effective

High performance steel with its unique chemical and physical properties facilitates economical fabrication practices of steel bridges. Its improved weldability, combine with its enhanced toughness and enhanced weathering characteristics, provide designers and owners with an option that can realize substantial savings in the overall cost of structures. Some owners have reported a 10% savings in cost of fabricated steel, based on reduced weight of steel.

### 15.2 HPS has Improved Weldability

Improved weldability of HPS does not require expensive preheat or other special welding considerations.

### 15.3 HPS has improved Toughness

Significantly higher fracture toughness of HPS minimizes sudden brittle failures of steel bridges in extreme low service temperatures. Its greater crack tolerance increases the available time window to detect and repair cracks before the structure might become unsafe.

### 15.4 Hybrid Design

The use of hybrid girder design appears to offer the most economical use of high performance steel.

In conclusion, High Performance Steel (HPS) with its improved weldability, improved toughness, improved corrosion resistance, and improved fabricability will provide cost-effective, more durable and more reliable bridges.

## 16.REFERENCES

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