PRODUCTION OF HIGH PERFORMANCE STEELS FOR U.S.A. BRIDGES

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Abstract

In 1996, the United States initiated the use of High Performance Steels (HPS) for bridge construction after a joint industry-government-academia research effort. A brief review of this development effort for high strength 50-100 Ksi, (345 to 690 MPa yield strength), improved weldability, high toughness and improved weathering (atmospheric corrosion resistant) steels is presented. This includes processing, properties and fabrication data. Currently, HPS-50W and HPS-70W grades are available and the HPS-100W is in development. The results of current production are reviewed. Future activities of the joint HPS effort, which includes steel, welding, corrosion and design-related issues, are discussed.

Introduction

In 1992, the U.S. Federal Highway Administration (FHWA) initiated an effort with the American Iron and Steel Institute (AISI) and the U. S. Navy (Navy) to develop new high performance steels (HPS) for bridges. The driving force for this project was the need to develop improved higher strength, improved weldability, high toughness steels to improve the overall quality and fabricability of steels used in bridges in the United States. It was furthermore established that such steels should be "weathering". By this is meant the ability to perform without painting under normal atmospheric conditions.

In the United States, the principal steel specification for bridges is American Society for Testing and Materials (ASTM) A709. Currently, in this specification, there are steel grades with minimum yield strengths (Y.S.) of 36, 50, 70, 100 Ksi (250, 345, 485 and 690 MPa). These minimum yield strengths also serve as the grade identity. Furthermore, when the steel has a weathering capability, the letter "W" is attached to the grade number. For example, grades 50W, 70W, and 100W .

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To guide the HPS program, a Steering Committee was established with representatives of the three noted groups, as well as bridge fabricators, welding consumable suppliers and university representatives. It was decided by the Steering Committee that the 70W and 100W grades should be the first candidates for improvement to meet the definition of High Performance Steel.

In the United States, Charpy V-Notch (CVN) impact testing requirements for bridge steels were developed by dividing the country into three zones. These zones range from the northern climates (known as Zone 3) to the southern climates (known as Zone 1) and have specific CVN testing temperature requirements. It was decided by the Steering Committee that the goal for HPS design would be to develop a steel that could meet the most critical requirements of Zone 3.

Research Program

The goals of the research program, as established by the Steering Committee, were to develop 70W and 100W weathering steel grades, with toughnesses meeting Zone 3 with significantly improved weldability. This is detailed in Table 1. These goals represent the strength level and the aggressive CVN toughness requirements felt important for these improved steels. The additional key goal of the program was to develop improved weldability steels, meaning that lower carbon and carbon equivalent levels would be required. Referring to Figure 1, known as the Graville Diagram (1), new steels were needed which improve upon the traditional range of carbon and carbon equivalent levels to those noted for HPS grades in Zone 1 of this diagram.

Also, the requirement that these new steels be able to demonstrate weathering characteristics in atmospheric environments meant that the current grades 70W and 100W should be used as a basis for the new grades. These grades contain elements that are important to providing weathering characteristics such as Cr, Cu, Ni and Mo. Predictive equations are available in ASTM G101 (2) to establish the minimum alloy content required in order to be defined as a weathering steel. An improved set of predictive equations have also been developed by Townsend (3), which are more useful for higher levels of the key alloy elements. These will soon be added to G101.

To provide improved toughness levels, a steel with lower sulfur levels is also needed. It was decided that the goal for these grades would be a 0.006% maximum sulfur level with calcium treatment for inclusion shape control.

Initial studies on candidate compositions for HPS were evaluated at steel company research laboratories using small laboratory sized heats. These initial studies defined the ability of a candidate steel composition to meet the goal properties. After identifying chemistries for these grades and the processing needed, full-scale mill heats were prepared for the candidate chemistry and full sized plates produced for evaluation and girder tests. Eventually, a demonstration bridge was identified for initial use of the grade.

Results

HPS-70W

The A709 Grade HPS-70W was the first one developed and commercialized in the HPS program. This grade is now also present in ASTM A709-2000 (4). The chemistry is shown in Table 2 compared to the Grade 70W that it replaces. HPS-70W is produced by quenching and tempering (Q&T) or Thermo-Mechanical-Controlled Processing (TMCP). The improvement in Charpy-V-Notch (CVN) impact properties of HPS-70W over 70W is shown in Figure 2 for Q&T production. More detailed presentations of Q&T HPS-70W properties have been presented previously (5). Because Q&T processing limits plate lengths to 50 ft. (15.2 m) in the U.S., TMCP practices have been developed on the identical HPS-70W chemistry to produce longer plates to 2" (50 mm) thick. The differences in the Q&T and TMCP processing are shown schematically in Figure 3. The properties for three initial projects using TMCP are summarized in Figure 4. Currently, HPS-70W plates produced by TMCP are available to 1500" (38 m) long depending on weight.

The improved weldability of HPS-70W has been demonstrated to allow welding with limited preheat requirements to 2-1/2 in. (64 mm) thick, whereas the traditional 70W required preheat at thicknesses over .75 in. (19 mm). To allow this improved weldability, new welding consumables were developed for submerged arc welding for low hydrogen conditions (6). The fabrication practices for use of HPS-70W were summarized in a document now available at: www.steel.org/ infrastructure/bridges/high_performance/hpsguide. To date, 17 bridges are open to traffic using HPS-70W, 9 more are in fabrication and over 40 more are in design across the U.S.A.

HPS-50W

With the success of the introduction of HPS-70W, a number of bridge owners requested an HPS version for the more common 50W grade. They were interested in the improved weldability and toughness. Steel companies established that an HPS-50W could be provided from the exact chemistry of HPS-70W when processed using conventional hot-rolling or controlled rolling (see Figure 3).

HPS-100W

The higher strength HPS-100W was a part of the original research program and was an improved version of the ASTM A514 grades. Currently, a Cu-Ni based grade developed with Lehigh University is in "mill trial" evaluation by the steel companies (7). Plates from 1/4" to 2-1/2" (6.4 – 64 mm) and seamless tubes are being produced. The chemistry of the first heat is shown in Table 3.

Improved Weathering Steels

Recent developments in Japan have reported improved "coastal" weathering steels (8). These grades have higher alloy levels than traditional weathering steels and are reported to perform well in modest chloride environments. Because of the higher alloy levels, the current G101 predictive equation cannot be used. However, the Townsend formulae can (3). These Japanese improved weathering steels are compared to HPS-70W and HPS-100W in Figure 5. The Cu-Ni HPS-100W is predicted to have the best performance in atmospheric corrosion.

Steel Specifications

Currently, ASTM A709-00 is the most up-to-date ASTM version. Although not in the ASTM 2000 book, this specification is available from ASTM directly or from their web site www.astm.org. AASHTO M270-00 is now equivalent to ASTM A709-00. Both contain the revision to lower minimum ultimate tensile strengths and wider chemistry ranges for HPS-70W, as shown in Tables 1 and 2. The ASTM Committee is currently reviewing the addition of a Grade HPS-50W and the use of TMCP and other practices for producing both HPS-50W and HPS-70W. It is expected these revisions will be available in 2001.

Future Research Program

The HPS Program in the U.S.A. is continuing with funding from the steel companies and the State and Federal governments. Areas to be addressed are focused in four areas:

Steel: finalize the development of HPS-100W.

Welding: evaluate the use of different welding methods - gas metal arc welding (GMAW) and electroslag welding (ESW); develop optimized welding consumables for HPS-100W.

Corrosion: establish whether accelerated test methods are appropriate for evaluating improved weathering steels; add alternative weathering predictive equation to ASTM G101; evaluation of improved weathering steels.

Design: establish via experimental and analytical techniques whether the design constraints for high strength steels can be removed, so that new designs can take full advantage of the use of HPS.

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Table 1
Property Goals for HPS Program

	*HPS-70W**	*HPS-100W*
	Up to 4" (101 mm)	*Up to2" (51 mm)*
Yield Strength, ksi (MPa) minimum	70 (485)	100 (690)
Ultimate Tensile Strength, ksi (MPa)	85-110 (586-760)	110-130 (760-895)
CVN of 35 ft.-lbs. (48 J)	-10°F (-23°C)	-30°F (-34°C)

* changes per A709-00

Table 2
Comparison of Chemistries for Traditional and HPS Versions of 70W

		C	*Mn*	*P*	*S*	*Si*	*Cu*	*Ni*	*Cr*	*Mo*	*V*
Old 70W											
	Min.	-	.80	-	-	.25	.20	-	.40	-	.02
	Max.	.19	1.35	.035	.04	.65	.40	.50	.70	-	.10
HPS-70W (1)											
	Min.	-	1.10	-	-	.30	.25	.25	.45	.02	.04
	Max.	.11	1.35	.020	.006	.50	.40	.40	.70	.08	.08

(1) Calcium treated for inclusion shape control, also requires .010 - .040 A1 and .015 N max.

Table 3
Comparison of Chemistries for Traditional and HPS Versions of 100W

	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V
Traditional 100W (2)										
Min.	.10	.60	-	-	.15	.15	.70	.40	.40	.03
Max.	.20	1.00	.035	.035	.35	.50	1.00	.65	.60	.08
HPS-100W Candidates										
A514F Mod. (1,3)	.11	.85	.015	.003	.30	.33	.85	.54	.46	.04
Cu-Ni (1,4)	.060	.99	.005	.002	.27	.98	.75	.51	.50	.059

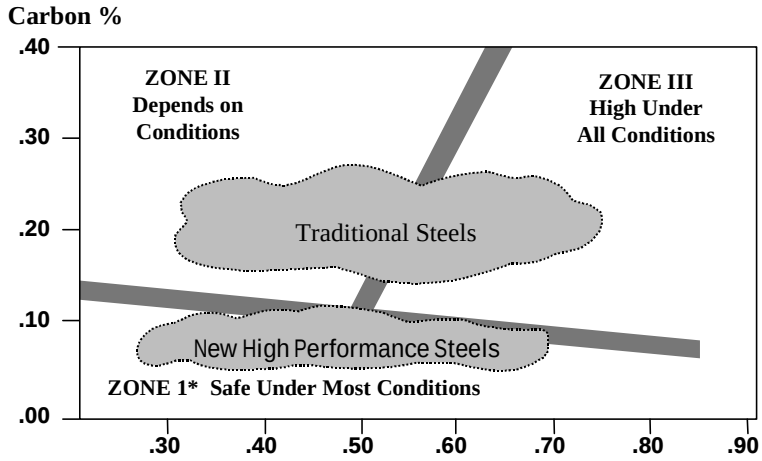
(1) Calcium treated for inclusion shape control

(2) 2-1/2" (65 mm) max. thickness

(3) contains .001B

(4) contains .020 Nb

Figure 1
The Graville Weldability Diagram
Susceptibility to HAZ Cracking of Plate Steels



$$CE = C + \frac{Mn + Si}{6} + \frac{Ni + Cu}{15} + \frac{Cr + Mo + V}{5}$$

***High Strength Welding Consumables May Require Additional Care**

Figure 2
Comparison of Properties of HPS-70W to Old 70W

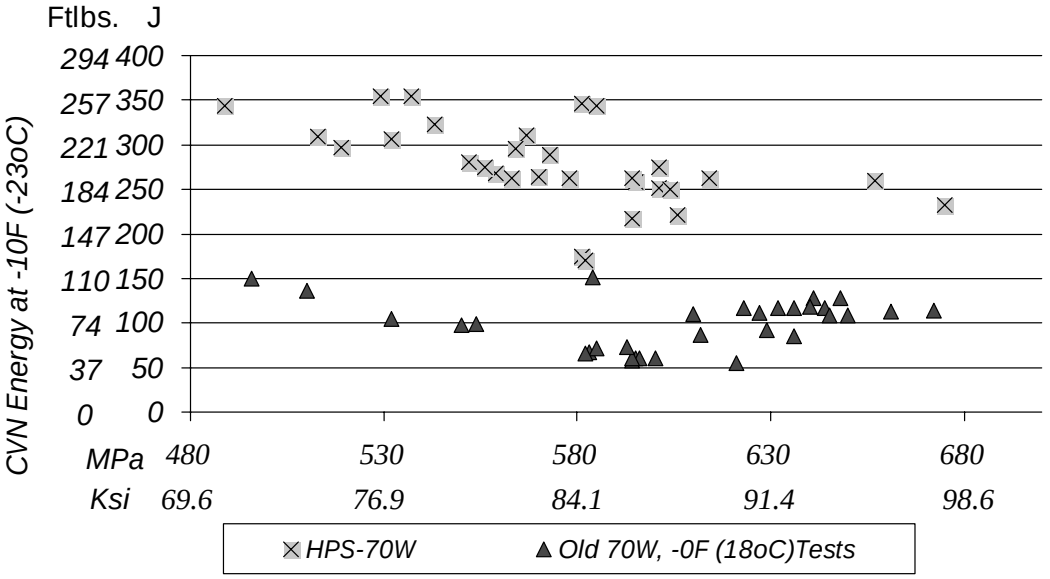


Figure 3
Processes for Producing Plate Steels

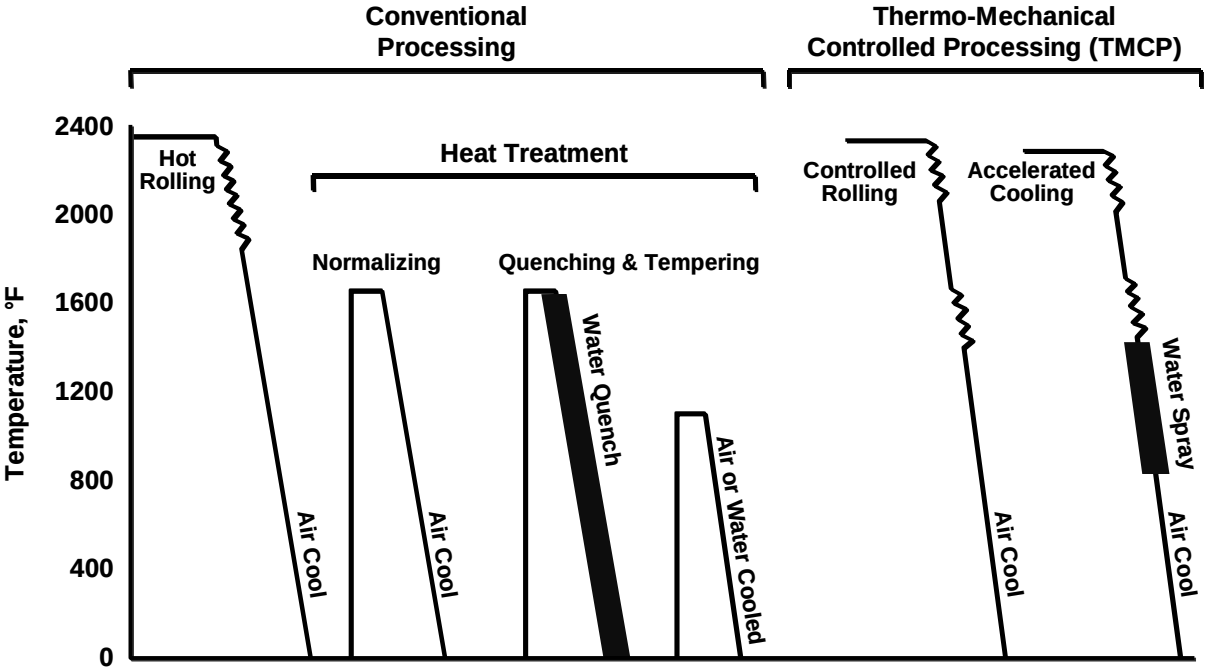


Figure 4
TMCP HPS-70W
0.5 - 0.59” Thick Plate Projects

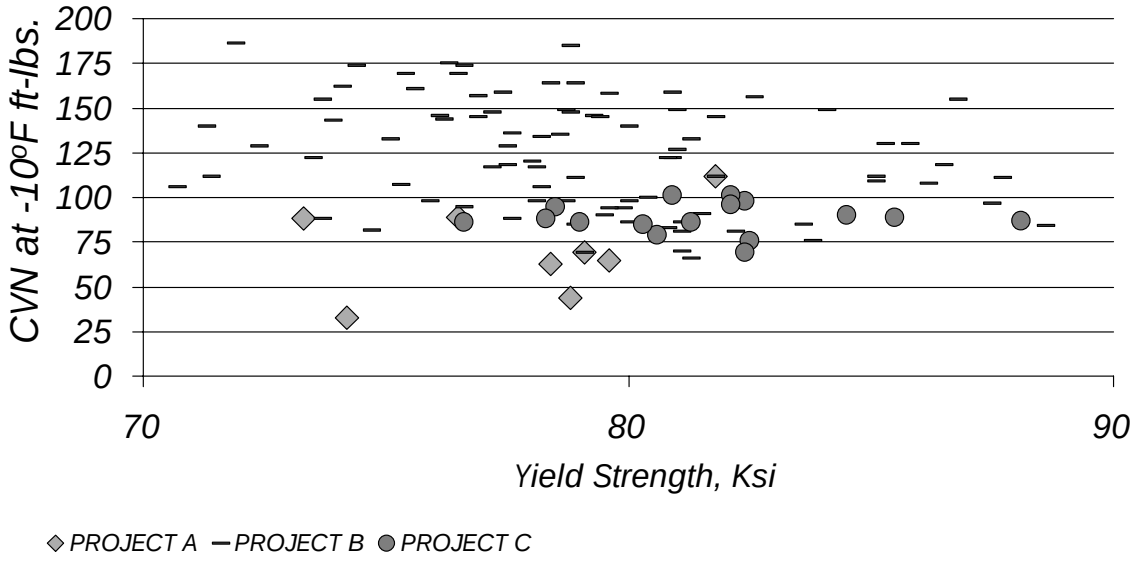
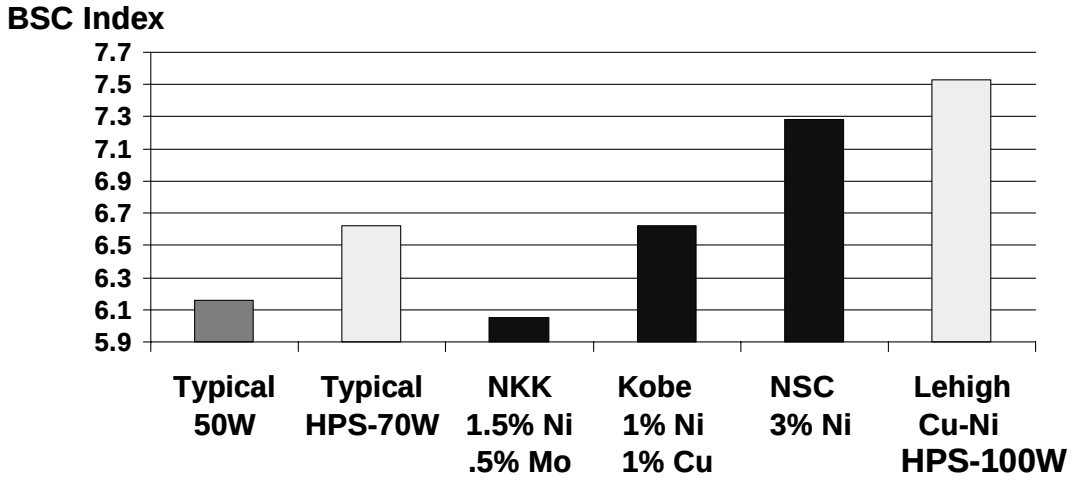



Figure 5
Comparison of Improved Weathering Steels
Ranking Using Bethlehem Equations