Steel
Market Development
Institute

GUIDE SPECIFICATION FOR

HIGHWAY BRIDGE FABRICATION

WITH HIGH PERFORMANCE STEEL

Third Edition

April 2011

GUIDE SPECIFICATION FOR HIGHWAY BRIDGE FABRICATION WITH HIGH PERFORMANCE STEEL

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I. INTRODUCTION

The intent of this *Guide Specification for Highway Bridge Fabrication With High Performance Steel, Third Edition,* hereafter referred to as the *HPS Fab Guide,* is to provide owners, designers and fabricators with the latest recommended methodology to fabricate and weld structures using ASTM A709 or AASHTO M270, Grade HPS 70W (HPS 485W) steel, referred to hereinafter as HPS 70W. The *HPS Fab Guide* is recommended for use until such time that other industry codes and specifications have included this product and have provided the necessary regulatory provisions to successfully fabricate bridges. The *Third Edition* is based on continued research and experience with fabrication and welding, and will be updated as additional research is conducted and additional experience is gained. The latest in research and experience with HPS 70W steel may be obtained by contacting the Steel Market Development Institute, a business unit of the American Iron and Steel Institute (AISI), at www.smdisteel.org.

HPS 70W is now furnished in as-rolled or control-rolled condition, thermo-mechanical control processed (TMCP) or quenched and tempered (Q&T) steel plates. Research continues to be conducted under a cooperative agreement sponsored by the Federal Highway Administration (FHWA), the U.S. Navy, and the Steel Market Development Institute. A High Performance Steel Steering Committee and a Welding Advisory Group, including representatives of steel plate manufacturers, welding consumable manufacturers, steel bridge fabricators, bridge owners, industry, academia and other experts, oversees research and development of High Performance Steel, and monitors its use. Appendix B contains a partial list of reports supporting research findings.

High Performance Steel has made a very rapid entry into the bridge industry. The first HPS 70W bridge was placed in service in December 1997, only three years after the onset of the cooperative research effort. Within the next four years, over 30 bridges were placed in service that have incorporated HPS 70W exclusively in steel plate girders, as part of homogeneous, mixed or hybrid plate girders, or in floor systems, deck trusses, and suspension bridges totaling ½ million square feet of deck area. Thirty-four owners, including states, authorities and other agencies, chose to take advantage of HPS 70W in approximately 140 steel bridges during this period.

There may be length, width or thickness limitations when using these alternately produced products, based on manufacturer specific capabilities. In addition, some of the required mechanical properties of HPS 70W may not be achieved in the non-quenched and tempered plates above some given thickness, depending on mill capability.

Initially, submerged arc welding (SAW) and shielded metal arc welding (SMAW) were the only processes recommended for welding high performance steel. Based on research, certain consumables for the flux cored arc welding (FCAW) and gas metal arc welding (GMAW) processes are now included. In addition, the *HPS Fab Guide* recommends specific consumables that have demonstrated that they are capable of successfully producing acceptable quality welds. In general, research and experience have shown that the potential for hydrogen induced cracking is minimized when diffusible hydrogen is controlled to a maximum of H8**.**

As additional welding processes and consumables are evaluated, the *HPS Fab Guide* will be updated to include those recommended for welding HPS 70W steel.

All references made hereafter to AWS D1.5 shall mean the *AASHTO/AWS D1.5M/D1.5:2002 Bridge Welding Code*.

1.1 Fabrication With HPS

The superior toughness of HPS 70W steel, combined with the requirements specified herein, suggest that fabrication in accordance with this *HPS Fab Guide* will produce structural members that meet Fracture Critical Member (FCM) specifications. At this time, it is necessary to fabricate fracture critical members, when identified as such in the contract documents, in accordance with AWS D1.5, Section 12, *AASHTO/AWS Fracture Control Plan (FCP) for Nonredundant Members*. Otherwise, fabrication of conventional, non-fracture critical HPS 70W components can be successfully completed when work is done in conformance with AWS D1.5 combined with the recommendations of this *HPS Fab Guide*. It is important to keep in mind that the *HPS Fab Guide* recommends consumable handling in accordance with AWS D1.5, Section 12.6.5 for the SMAW process, Section 12.6.6 for the SAW process, and Section 12.6.7 for the FCAW and GMAW Metal Cored process, to control the diffusible hydrogen levels to H8 maximum. Otherwise, no other provisions of the Fracture Control Plan are recommended, unless the component is specifically designated a FCM.

2. BASE METAL MATERIAL PROPERTIES

Table 1 provides a comparison of the chemical composition of former ASTM A709, Grade 70W steel, ASTM A709-97^{01} and ASTM A709-01 Grade HPS 70W steel. Note the more controlled ranges of allowable alloy elements and lower sulfur, phosphorus and carbon levels for HPS 70W steel, and development of HPS 70W chemistry to the most current specification.

HPS 70W steel must be made using a low-hydrogen practice, such as vacuum degassing; controlled soaking; cooling of ingots, slabs, or plates; or a combination thereof. Hardenability is much better controlled as a result of the tighter ranges for alloying elements.

2.1 Weathering

HPS 70W corrosion resistance is calculated using the heat analysis equation in ASTM G101, *Estimating the Atmospheric Corrosion Resistance of Low-Alloy Steels.* The higher the index, I, the more corrosion-resistant the steel. The minimum Corrosion Index, I, for HPS 70W steel is a 6.5, compared to a minimum of 6.0 for 50W and former 70W steels. Therefore, it is assumed that HPS 70W steel will have superior corrosion resistance than 50W and former 70W, although this is unsubstantiated by tests at this time.

Like other weathering steels, there is a potential for atmospheric corrosion rates to increase in applications that subject high performance steel to continuously wet environments for prolonged periods of time, or to corrosive chemicals, including deicing salts.

2.2 Mechanical Properties

Table 2 compares the initial ASTM Specification requirements of HPS 70W with more recent revisions to the specification as HPS has developed. One of the most significant advantages of HPS 70W steels is its enhanced toughness. Minimum specified Charpy V-notch (CVN) values for HPS 70W steels with thicknesses up to 4 inches equal or exceeds Zone 3 requirements for both fracture critical and non-fracture critical applications. CVN values in excess of 100 ft-lb at -10^{0}F are consistently achieved for these steels.

Contract plans and specifications must specify each component requiring CVN testing, the applicable test temperature zone, although the same CVN values are required for all three zones, and whether FCM requirements apply. Minimum Charpy V-notch toughness requirements should be specified as described in the AASHTO *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*, 1999 Interim Edition, or later.

2.3 Weldability

Weldability of HPS 70W may be improved when diffusible hydrogen is controlled to a maximum of H_8 based on current studies. The relative differences in weldability between former Grade 70W and HPS 70W are illustrated in Figure 1, which plots the carbon content and carbon equivalent of both steels using the Hydrogen Control Method described in AWS D1.5, Appendix VIII4. Note that in the majority of the cases, HPS 70W material is within Zone I, *Safe Under Most Conditions* field, while a significant amount of the former Grade 70W material is within Zone II and Zone III. However, be aware that HPS 70W can have certain conditions that are within Zone II and especially Zone III where crack susceptibility is high under all conditions.

(<u>Note</u>: The term *zone* used here is different than the AASHTO temperature zone for toughness requirements, i.e., Zone I is defined in AWS D1.5, Article VIII4.5.2.1 as "Cracking is unlikely but may occur with high hydrogen or high restraint.")

AASHTO Specification M-270M/M-270, Section 1.2, states, "All steels covered by this specification are weldable. Welding procedures must be selected that are suitable for the steel being welded and its intended use." Note the emphasis on use of proper procedures.

ASTM Standard Specification A709/A709M, Section 1.3, states, "When the steel is to be welded, it is presupposed that a welding procedure suitable for the grade of steel and intended use or service will be utilized. See Appendix X3 of Specification A6/A6M for information on weldability."

ASTM A6/A6M, Section X3, "Weldability of Steel," states in part: "Difficulties arise in steel when the cooling rates associated with weld thermal cycles produce microstructures ... that are susceptible to brittle fracture, or more commonly, hydrogen induced (or cold) cracking." High restraint is uncommon in properly detailed girder bridges. The primary concern is for hydrogen control during the welding of steels to prevent cold cracking. Appendix X3 broadly characterizes weldability as "the relative ease with which a metal can be welded using conventional practices." Appendix X3 also notes that, other than the chemical composition and carbon equivalent of a steel, cold cracking can be influenced by the following:

2.3.1 Joint restraint/base metal thickness,
2.3.2 Filler metal and base metal strength compatibility,
2.3.3 Diffusible hydrogen content of deposited weld metal,
2.3.4 Preheat and interpass temperatures,
2.3.5 Filler metal and base metal cleanliness,
2.3.6 Heat input, and,

The time delay between successive weld passes is also a factor that can influence cold cracking.

The safety of steel bridges includes resistance to brittle fracture. One way to minimize the potential for fracture is to eliminate the conditions that cause hydrogen-induced cracks. Weld hardness and toughness may be controlled by selection of proper filler metal and welding variables, but the base metal and HAZ hardness are more dependent on the sensitivity of the base metal to high cooling rates that cause unacceptable hardening. The chemical composition of HPS 70W steel was designed to protect against excessive hardness in both the HAZ and base metal during welding and subsequent cooling.

Awareness and use of good hydrogen control practices, along with proper procedures, is absolutely essential to successful welding of HPS 70W steel. Fabrication in accordance with AWS D1.5 in combination with this *HPS Fab Guide* substantially increases the assurance that hydrogen levels will be controlled by emphasizing each factor listed previously.

3. WELDING

Submerged arc welding (SAW) is the primary process used to join plates for bridge components in the United States today. Other processes, including shielded metal arc welding (SMAW), flux cored arc welding (FCAW) and gas metal arc welding (GMAW), are used for certain applications. All consumables should be handled in accordance with AWS D1.5, including Section 4, for all HPS applications, except that the maximum allowable diffusible hydrogen (H_d) in the weld will be 8mL/100g, regardless of the weld process used. When the reduced preheats of Table 3 are used, all consumables must be handled in accordance with the procedures described in AWS D1.5, Sections 12.6.5, 12.6.6 and 12.6.7 to ensure that diffusible hydrogen is controlled to a maximum H_d level of 4mL/100g. Alternatively, consumables may be handled according to the consumable manufacturer's recommendations if the consumable manufacturer recommends storage and handling procedures different than those of AWS D1.5 Sections 12.6.5, 12.6.6 and 12.6.7, and the consumable manufacturer will guarantee a maximum H_d of 4 ml/100 g when their recommendations are used. For the SAW process, fluxes received in undamaged hermetically sealed pails may be used right from the pail without baking. Flux received in moisture resistant bags shall be rebaked prior to use. When ordering consumables, the diffusible hydrogen level, H2, H4 or H8, should be specified.

Regardless of the weld process used, consumables or fabrication practices that produce weld deposits with H_d levels in excess of 8 mL/100g should never be allowed.

Welding procedures for HPS 70W steels must be qualified in accordance with AWS D1.5, Chapter 5, except as modified herein. The Code specifies that only low-hydrogen welding practices be used.

Procedure qualification tests should be based on the appropriate temperature zone for the project site. HPS 70W steel meets AASHTO Zone 3 requirements, but welds need only meet the site requirements.

3.1 Preheat and Interpass Temperature

Research and experience has demonstrated that control of diffusible hydrogen (H_d) to 4 mL/100g or less using the procedures and consumables recommended herein can easily be achieved in fabrication shops under actual fabrication conditions. Therefore, controls must be implemented to ensure a maximum H_d of 4 mL/100g for all matching strength submerged arc welding of HPS 70W steel when the reduced preheats of Table 3 are used, unless specific evidence is presented by a fabricator that satisfactory welds can be produced at higher levels of diffusible hydrogen up to a maximum of 8 mL/100g.

Diffusible hydrogen levels greater than 4 to a maximum of 8 mL/100g must only be allowed when the preheat requirements of AWS D1.5, Table 4.4 for Group IV materials are used.

To summarize, the minimum preheat and interpass temperature may be in accordance with Table 3 when using matching strength consumables producing an H_d of 4ml/100g maximum. For H_d levels greater than 4ml/100g up to a maximum of 8ml/100g, the minimum preheat and interpass temperature must be in accordance with AWS D1.5, Table 4.4 for Group IV materials.

The maximum interpass temperature for welding HPS 70W steel is 450^0F (230^0C).

3.2 Consumables for Matching Strength Welds

Consumables used for matching strength welds are generically classified in AWS D1.5, Tables 4.1 and 4.2. However, research has suggested that when welding HPS 70W steel, consumables that would meet the generic specifications for Grade 70W steels will not provide weldments with diffusible hydrogen levels low enough to avoid hydrogen cracking. As a result, continuing research has determined the consumables that would be expected to provide sound, crack-free welds using conventional low hydrogen welding practice. The following sections list recommended manufacturer-specific consumables for producing matching strength welds for each process.

3.2.1 Submerged Arc Welding (SAW)

The SAW consumable combination LA85 electrode with Mil800HPNi flux, manufactured by the Lincoln Electric Company, has produced welds that meet all of the requirements specified in AWS D1.5 and this *HPS Fab Guide* using the minimum preheat and interpass temperatures as listed in Table 3.

Alternate, matching strength, manufacturer-specific electrode/flux combinations will be allowed, subject to the restrictions of 3.2.5, providing they conform to AWS electrode/flux Classification F9A4-EXXX-X, with optional supplementary moisture resistance designator H_4 or less, as described in AWS A5.23, *Specification for Low Alloy Steel Electrodes and Fluxes for Submerged Arc Welding*, with 1% Nickel, minimum, in the weld deposit.

3.2.2 Flux Cored Arc Welding (FCAW)

Matching strength FCAW consumables TM-95K2 (AWS Classification E90T5-K2) with a minimum heat input of 25 kJ/in, manufactured by ITW/Hobart, and DS II 101H4M with a minimum heat input of 40 kJ/in, manufactured by ESAB, have produced weldments in research and manufacturers' studies that meet all of the requirements specified in AWS D1.5 and this *HPS Fab Guide* using the minimum preheat and interpass temperatures as listed in Table 3. It is further recommended that fabricators handle these consumables in accordance with AASHTO/AWS D1.5, Section 12.6.7, in addition to strictly following manufacturers' more stringent recommendations.

Alternate, matching strength, filler metals are not recommended at this time. Additional recommendations will be listed on the Steel Market Development Institute website, www.smdisteel.org, as research and experience progresses.

3.2.3 Gas Metal Arc Welding (GMAW)

Matching strength GMAW Metal-Core consumable Metalloy 90 (AWS Classification E90C-G) with a minimum heat input of 40 kJ/in, manufactured by the ITW/Hobart, has produced weldments in research and manufacturers' studies that meet all of the requirements specified in AWS D1.5 and this *HPS Fab Guide* using the minimum preheat and interpass temperatures as listed in Table 3. It is further recommended that fabricators handle these consumables in accordance with AWS D1.5, Section 12.6.7, in addition to strictly following the manufacturers' more stringent recommendations.

At this time, only tubular consumables are recommended, and pulsed wave current is not allowed.

Alternate, matching strength, filler metals are not recommended at this time. Additional recommendations will be listed on the Steel Market Development Institute website, www.smdisteel.org, as research and experience progresses.

3.2.4 Shielded Metal Arc Welding (SMAW)

Moisture and exposure of shielded metal arc welding electrodes is generally easier to control since the product is delivered in hermetically sealed containers that can be opened when needed. To minimize the potential for hydrogen related problems, only electrodes with the designators **HZ** and **R**, indicating a moisture-resistant coating with diffusible hydrogen level, should be accepted. For matching strength welds, E 9018 HZR electrodes with diffusible hydrogen levels of H4 or H8, depending on level of preheat, should be used. Electrodes must conform to AWS A5.5, *Specification for Low-Alloy Steel Covered Arc Welding Electrodes*.

If SMAW electrodes are not maintained in accordance with Section 12.6.5, the higher preheats listed in Table 3 for 8 mL/100g diffusible hydrogen will be required.

3.2.5 Welding for Hybrid Designs

Consumables listed in AWS D1.5, Table 4.1 for Grade 50W base metal are considered to be matching strength for hybrid designs where HPS 70W base metal is joined to 50W base metal. To minimize the potential for cracking, even with consumables selected from Table 4.1, consumables must conform to the diffusible hydrogen requirements of the AWS Filler Metal Specification with diffusible hydrogen levels not to exceed H_8.

3.2.6 Alternate Consumables

When alternate matching strength consumables are allowed, the owner should require the fabricator to perform the full range of weld tests required by Section 12.6, in addition to other WPSs required by Section 5 of AWS D1.5. Minimum preheat and interpass temperatures must be in accordance with Table 3, if the lower preheat is to be used in the work. However, fabricators may choose to use the preheat specified in AWS D1.5, Table 4.4 when welding HPS 70W with any consumables, providing the WPS is clearly marked that Table 4.4 preheat is required, and the lower allowable preheats specified in Table 3 of this *HPS Fab Guide* are not allowed.

In addition, diffusible hydrogen (H_d) testing must be conducted by the manufacturer in accordance with AWS A4.3, *Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding,* to demonstrate that welds can be produced with a maximum diffusible hydrogen level of 4 mL/100g. Test results in excess of 4 mL/100g require a retest, with or without revised welding parameters.

Procedure Qualification Records should not be transferable to other fabricators. However, fabricators with multiple plants audited as a single facility by the American Institute of Steel Construction (AISC) as a part of their Quality Certification Program, or other owner-approved Quality Assurance program, should be considered one location. When operated with common welding equipment, welding training, and supervision, they should be allowed to perform PQR testing only once per combination of consumables as if operating at one location. Multiple plants not included in the AISC or other single audit should be considered separate facilities and PQR tests should be required for each plant.

3.2.7 Qualification Test Requirements

Filler metal procedure qualification test requirements for joining HPS 70W plates to HPS 70W plates must be in accordance with AWS D1.5, Table 4.1 or 4.2, as applicable, for Grade 70W base metal. Qualification, Pretest and Verification Test Requirements for welding HPS 70W plates must be in accordance with AWS D1.5, Section 5.7, *General Requirements for WPS Qualification*.

3.3 Consumables for Undermatched Weld Strength

AWS D1.5, Section 2.1.6 and General Notes for Tables 4.1 and Table 4.2 permit undermatched weld metal strength for all fillet and PJP welds when consistent with design requirements, and limited CJP welds for limited applications.

Fillet welds comprise the majority of the welding on a typical bridge. The use of undermatched consumables is highly recommended for all fillet welds joining HPS 70W to HPS 70W plates to reduce the potential for hydrogen cracking. To achieve this, the engineer should specify where undermatched fillet welding is acceptable on the contract drawings.

For the SAW and SMAW processes, filler metals recommended for Grade 50W base metal should be specified to ensure the welds are undermatched but not significantly understrength, i.e., minimum ultimate tensile strengths are near 70 ksi (485 MPa), and weathering characteristics will be similar for unpainted applications.

For the FCAW process, undermatched consumable TriMark TM-771 (AWS Classification E71T-12J) with a minimum heat input of 40 kJ/in, manufactured by Hobart/ITW, UltraCore 712C (AWS Classification E71T-12J) with a minimum heat input of 40 kJ/in and UltraCore 81Ni1C-H (AWS Classification E81T1-Ni1CJ-H4) manufactured by Lincoln Electric have produced weldments in research and manufacturers' studies that meet all of the requirements specified in AWS D1.5 and this *HPS Fab Guide* using the minimum preheat and interpass temperatures as listed in Table 3. Alternate, undermatched FCAW consumables are not recommended at this time. Additional recommendations will be listed on the Steel Market Development Institute website, www.smdisteel.org, as research and experience progresses.

For undermatched SMAW applications, E7018R or E8018-C3R electrodes are acceptable, as applicable, and their use is encouraged. Electrodes shall be in accordance with AWS D1.5, Table 4.3, except for single pass fillet weld applications described in Section 3.4, and SMAW welds that will be fully incorporated into a finished weld.

3.4 Fillet Weld Applications

Single pass fillet welds up to a maximum leg size of 5/16" are adequately diluted by the base metal chemistry during the welding process. Therefore, consumables for these single pass fillet welds do not have to meet the alloy requirements of AWS D1.5 for weathering as defined by Section 4.1.4, Table 4.3, or Tables 4.1 and 4.2 Note 3.

3.5 Heat Input

The research conducted indicates that control of heat input is very important to ensure sound welds and to minimize the effects on HPS 70W strength, toughness and weldability. These limits are more stringent than AWS D1.5, but are achievable and economical with proper welding procedures.

The recommended heat input (HI) limits for the SAW process are 40 kJ/in, minimum, and 90 kJ/in, maximum, as determined using AWS D1.5 Section 5.12. For all other processes, heat input is as recommended for manufacturer specific consumables at this time, as described in Sections 3.2.2, 3.2.3 and 3.2.4.

3.6 Heating for Curving, Cambering or Straightening

Short-term applications of heat for purposes of heat curving, heat straightening, or heat camber and sweep adjustment is limited to 1,100 °F (600^{0}C) maximum. This limit should not be further reduced in accordance with other specifications when heating HPS components.

3.7 Backing

AWS D1.5, Section 5.4.5 requires steel backing material for groove welding of PQR test plates to be of the same specification and grade as the weld test plates. Since PQR testing is often done in advance of the mill order, finding the HPS 70W material may be difficult to obtain in small quantities, and often the fabricator has to mill it from thicker plates. AWS D1.5, Section 3.13.1 allows backing and weld tabs to be cut from Grade 70W (485W), 50 (345), 50W (345W) or 36 (250) for production welding any of the qualified steels. This same provision should be considered for welding of HPS 70W steel PQR test plate assemblies. This *HPS Fab Guide* recommends the use of HPS 70W for backing whenever possible, and further recommends the substitution of Grade 50W for HPS 70W backing material for qualification testing or production welding when necessary.

Research has shown that backing material with high sulfur content could cause micro-cracking in the initial passes of groove welds. Thus, it is recommended that the sulfur content of backing material be limited to 0.025% maximum for ASTM A709, Grade 50W (345W), in lieu of the 0.05% allowed by specification.

4. FABRICATION EXPERIENCES AND TECHNIQUES

HPS 70W has made a very rapid entry into the bridge industry, in part because of the willingness of all parties to share technical information and experiences. When difficulties were encountered, they were immediately addressed by the HPS Steering Committee and its subcommittees, and quickly resolved. All interested parties were informed, and valuable experience was gained.

The first use of HPS 70W steel was to fabricate small girders for laboratory testing. No difficulties were encountered in either plate cutting or welding with SAW or SMAW.

The first project using HPS 70W steel was to fabricate plate girders for a bridge that is now in service. Although this bridge utilized HPS 70W steel, it was designed using Grade 50W steel, and consumables recommended for Grade 50W steel were used. Again, no problems were encountered in the welding. However, the fabricator initially reported that the material was more difficult to burn, drill and blast as compared to Grade 50W steels (Kirsch 1997). However, this problem seems to have been resolved and no similar complaints have been reported.

Another project, which was under fabrication at about the same time, reported difficulty removing mill scale, which was attributed to the Q&T heat treatment of the plates (Germanson 1998). This project included fabrication of girders for a bridge designed for the material's 70 ksi (485 MPa) strength. Matching strength welds were used throughout the girders. At the beginning of the project, the Procedure Qualification Test (PQR) plates were welded in accordance with AWS D1.5, and the weld deposits had very poor mechanical properties. A team of experts convened at the fabricator's plant, resulting in a complete change of welding consumables to eliminate obvious hydrogen-induced cracking. New PQR test plates were successfully fabricated using LA100 wire with Mil800H flux supplied by Lincoln Electric Company. The bridge is now open to traffic. Although these consumables were used initially to fabricate several bridges, they are now considered to be overmatched for the base metal and are no longer recommended by the manufacturer or this *HPS Fab Guide*, unless the preheats specified in AWS D1.5 are used.

Many more bridges have been fabricated and are carrying traffic. Careful records have been maintained to document fabrication experiences, good or bad, and to develop solutions for problems as they were encountered. Again, many of these bridges were designed and constructed with HPS 70W steel with matching strength welds. The following is a summary of fabricators' experiences:

(a) *Welding*: Butt joints normally use 2-inch-long weld runoff tabs at each end of the joint. When welding with the SAW combination of Lincoln LA100/Lincoln Mil800H, minor edge defects were discovered when the tabs were removed. The fabricator increased the length of the runoff tabs to 6 inches to allow the welding arc to stabilize before the parent plate was encountered and eliminated the discontinuities at the ends of the welds.

(b) *Automatic SAW opposed twin head welder (such as Ogden Dart)*: Flux provided was too coarse to flow smoothly through some equipment. Manufacturers have modified flux particle size and distribution as appropriate to ensure proper flow by the flux handling equipment.

(c) *Hole Drilling*: Significant dulling of bits was occurring at the beginning of a project, until the holes were liberally flooded with coolant/lubricant during the drilling process. This eliminated the drilling difficulties.

(d) *Hole Reaming*: As with the drilling, significant increase in the amount of lubricant applied solved the reduced productivity during reaming.

(e) *Mill Scale Removal*: Mill scale is more difficult to remove using a descaler from the quenched and tempered HPS 70W than from Grade 50W, most likely due to the heat treatment process. This was most pronounced during the mill scale removal in preparation for the web-to-flange welding. However, mill scale removal by blasting using a 60/40 shot/grit mixture was no more difficult than conventional steels.

(f) *Flame Cutting*: One fabricator found that increasing the burning machine speed improved the cutting performance, as opposed to the opposite experience reported by another fabricator.

(g) *Shearing*: There are no reports on shearing of HPS 70W plates. However, it is anticipated that shearing force requirements, compared to 50 ksi steel, will increase proportionally with the increase in material strength. Wear on shear cutting edges may also increase proportionally.

(h) *Handling*: HPS 70W girders will typically have lower weight and moments of inertia than girders fabricated from lower strength materials. This provides advantages for handling and shipping, but may require additional bracing for stability during transportation and erection. Also, as with all steels, chains used for lifting should all have softeners to prevent unnecessary gouges in plate edges.

(i) *Heat Curving*: AWS D1.5, Section 3.7.3 limits use of heat curving methods for Q&T steels to 1100^{0}F. Although preliminary research has shown temperatures as high as 1250^{0}F do not adversely affect the properties of the HPS 70W base metal, 1100^{0}F is still considered the limit until further investigation is completed (Teal 1999).

5. REPAIRS

Repairs to girders should be done in accordance with AWS D1.5, Section 3.7. Unless absolutely necessary to correct misplaced holes by welding, they should be left open. Alternately, the hole(s) may be filled with a A325 Type 3 high strength bolt(s). The welding requirements of AWS D1.5, Section 3.7.7.3 should not be applied for HPS 70W steel.

6. COST-EFFECTIVE HPS BRIDGES

The ultimate goal for the development of high performance steels is to provide owners with High Performance Bridges. There are many ways a designer can improve the cost-effectiveness of steel bridges that take full advantage of high performance steel without reducing its safety or long-term service life, including the use of hybrid girders combining HPS 70W with lower strength steels.

6.1 Hybrid Designs

Using a design strength level of 70 ksi in all components may not be efficient. Portions of a steel bridge may not require 70 ksi (485 MPA) strength levels. Additionally, serviceability limitations such as live load deflection, buckling or fatigue may dictate that a lower strength steel would be appropriate. Therefore, hybrid design is highly recommended for steel bridges utilizing HPS 70W. The term *hybrid* as used herein is defined as a bridge or girder designed and fabricated with different grades of steel, i.e. HPS 70W and 50W (345W). For areas of main girders that do not require 70 ksi strength material, Grade 50W should be used. This could include flange plates near end bearings or in positive moment sections, and web plates in positive moment areas or where shear is high and an unstiffened thicker 50W (345W) web is more economical than a stiffened, but thinner HPS 70W plate. Using 50W (345W) plates in these areas not only allows use of a lower unit cost material, but welding is more cost-effective since the lower strength plate determines the weld consumables to be used (Teal 1999).

Rolled shapes (angles, structural tees, etc.) are used primarily for diaphragms and crossframes, but are not available in HPS grades. Therefore, 50W (345W) material should be specified and used for these members.

6.2 Plate Sizes

All stiffeners and connection plates should be Grade 50W material whenever possible, consistent with the design requirements. They should be detailed using bar or flat stock [1] which may not be available in HPS 70W. Stiffeners generally represent small quantities of material, so premium prices apply if HPS 70W is specified.

6.3 Butt Splices

Currently, HPS 70W plate over two inches (50 mm) thick must be quenched and tempered to attain its required strength. Mill capabilities in the U.S. limit the maximum length of Q&T plates to 50 feet (15.24 m).

Thermo-mechanical controlled processing is routinely used to manufacture HPS 70W plate two inches and under in thickness. Plate length and width is restricted only by the capabilities of the mill; i.e., the plate is available in sizes generally comparable to 50W. Thus, for longer bridge girders, butt splices may be required only because of this length limit. Ideally, when butt splices required as a part of the normal flange optimization process are located at intervals less than 50 feet, there will be less cost. Designers must consider available material length limits and carefully select shop and field splice locations to minimize costs. Butt splices provide an opportunity to transition to thinner or lower strength plates and the hybrid design where applicable.

6.4 Fillet Welds Sizes

Generally, the size of fillet welds subject to shear stress in steel I-shaped girders and box girders will be the minimum size specified by AWS D1.5, Table 2.1 and *AASHTO LRFD Design Specification*, Table 6.13.3.4-1, unless design calculations dictate otherwise. Thus, only 1/4 in. and 5/16 in. fillet weld sizes should be used unless horizontal shear or transverse loads require a larger size. Also, design plans should specify where welds may be undermatched, and whether or not non-weathering consumables can be used for all single-pass fillet welds up to 5/16" leg size, consistent with code requirements.

6.5 Superstructure Replacement

HPS 70W steel may allow structure replacements at longer spans, eliminating the need for shoulder piers and increasing vertical clearance while maintaining the existing approach roadway profile (Teal 1999).

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[1] During the preliminary design stage, information from plate manufacturers and discussion with bridge fabricators should also be used as a basis for optimizing plate size selection and costs.

TABLE 1. Chemical Composition[a]

Element	ASTM A709, Former Grade 70W (485W) Composition, %	ASTM A709-97□1 Grade HPS 70W (HPS 485W) Composition, %	ASTM A709-01 Grade HPS 70W (HPS 485W) Composition, %
Carbon (C)	0.19 max	0.11 max	0.11 max
Manganese (Mn)	0.80-1.35	1.15-1.30	1.10-1.35
Phosphorus (P)	0.035 max	0.020 max	0.020 max
Sulfur (S)	0.04 max	0.006 max[*b*]	0.006 max[*b*]
Silicon (Si)	0.20-0.65	0.35-0.45	0.30-0.50
Copper (Cu)	0.20-0.40	0.28-0.38	0.25-0.40
Nickel (Ni)	0.50 max	0.28-0.38	0.25-0.40
Chromium (Cr)	0.40-0.70	0.50-0.60	0.45-0.70
Vanadium (V)	0.02-0.10	0.05-0.07	0.04-0.08
Molybdenum (Mo)	-	0.04-0.08	0.02-0.08
Aluminum (Al)	-	0.010-0.040	0.010-0.040
Nitrogen (N)	-	0.015 max	0.015 max

[a] Product analysis tolerances are listed in Table B of ASTM A6.
[*b*] The steel shall be calcium treated for sulfide shape control.

TABLE 2. Mechanical Properties

Property	ASTM A709-97□1 HPS 70W (HPS 485W)	ASTM A709-01 [a] HPS 70W(HPS 485W)
Plate Thickness	to 4 in. (100 mm)	to 4 in. (100 mm)
Min.Yield Strength[b]	70 ksi (485 MPa)	70 ksi (485 MPa)
Tensile Strength	90 - 110 ksi (620 – 760 MPa)	85 - 110 ksi (585 – 760 MPa)
Min. Elongation, 2 in.	19%	19%
Min. Toughness; CVN -non FCM	All Zones to 4 in. (100 mm) 25 ft-lb @ -10^0F (34 ft-lb @ -23^0C)	All Zones; to 4 in. (100 mm) 25 ft-lb @ -10^0F (34 ft-lb @ -23^0C)
Min. Toughness; CVN - FCM	All Zones to 4 in. (100 mm) 35 ft-lb @ -10^0F (48 ft-lb @ -23^0C)	All Zones to 4 in. (100 mm) 35 ft-lb @ -10^0F (48 ft-lb @ -23^0C)

a. Typical for ASTM A709-97[00a], HPS 70W (HPS485W) 0.2% offset

TABLE 3. Minimum Preheat and Interpass Temperature, ^{0}F (C), for HPS 70W (HPS 485W) [a]

Welding Process	H_d Max.	Thickness of Thickest Part at Point of Welding, in. (mm) [b]			
		To 3/4 Incl.	Over 3/4 to 1-1/2 Incl.	Over 1-1/2 to 2-1/2 Incl.	Over 2-1/2
SAW, SMAW [c]	4 mL/100 g	50 (10)	70 (20)	70 (20)	125 (50)
FCAW, GMAW [c, d, e]	4 mL/100 g	50 (10)	70 (20)	150 (65)	225 (110)
SAW, FCAW, GMAW, SMAW [d, e, f] SAW, SMAW of HPS 70W to lower strength grades of steel [f]	8 mL/100 g	50 (10)	125 (50)	175 (80)	225 (110)

[a] If satisfactory results are not achieved with the above minimum preheat and interpass temperatures during development of the Welding Procedure Specification (WPS), and an increased preheat temperature is used to provide a satisfactory Procedure Qualification Record (PQR), the higher preheat temperature should be the required minimum during bridge fabrication.

[b] The minimum preheat or interpass temperature required for a joint composed of different base metals and/or thicknesses should be based on the higher of the minimum preheat required by AWS D1.5, Table 4.4 or Table 3 above.

[c] Diffusible hydrogen of filler metal tested by manufacturer shall not exceed a H4 classification. Heat input should be limited as indicated in Section 3.5.

[d] Refer to AWS D1.5, Sections 12.5, 12.6 and 12.7 for handling requirements. Manufacturer's recommendations must be followed as a minimum.

[e] Pulsed GMAW shall not be allowed.

[f] Conforms to AWS D1.5, Table 4.4 for lower grades.

The Graville Weldability Diagram

Susceptibility to HAZ Cracking of HPS Bridge Steels

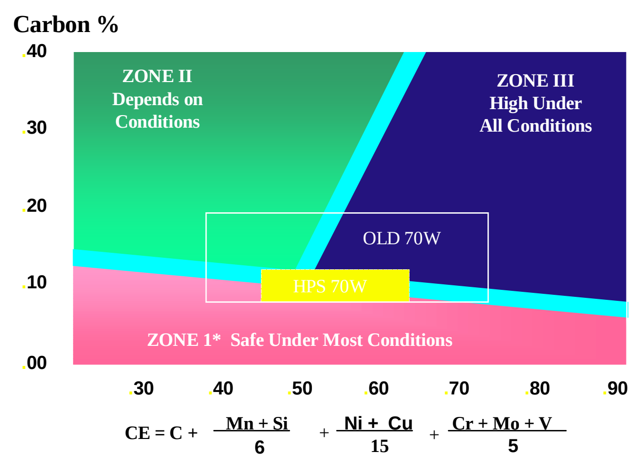

Figure 1

APPENDIX A

SPECIAL PROVISIONS:
FABRICATION WITH HPS 70W (HPS 485W) STEEL

1. DESCRIPTION:

1.01 Under this work, the Contractor shall fabricate, furnish and erect structural steel in accordance with the Contract documents.

1.02 This specification applies to the fabrication of bridge components using high performance steel plates furnished in one of the following conditions: as-rolled, controlled rolled, thermo-mechanical-controlled-processed (TMCP) with or without accelerated cooling, or quenched and tempered (Q&T), referred to hereafter as HPS 70W. Designs may be exclusively HPS 70W, or may be hybrid/mixed design using high performance steel plates in combination with high strength, low alloy steel plates and shapes, for welded or bolted applications in bridge construction.

1.03 All provisions of Section (   ) of the ***State Standard Specifications*** shall apply, except as modified on the plans or in this specification.

2. MATERIALS:

2.01 All steel, including HPS 70W, must comply with all provisions of the current ASTM A709/A709M, ***Standard Specification for Carbon and Low Alloy Structural Steel Shapes, Plates and Bars, and Quenched and Tempered Alloy Structural Steel Plates for Bridges*** except as modified herein. Supplementary Requirement S83, Non-Fracture Critical Materials Toughness Tests and marking, or S84, Fracture Critical Materials Toughness Tests and marking will apply, as appropriate, and must be specified with the mill order.

2.02 The Contractor is advised that quenched and tempered ASTM A709, Grade HPS 70W/HPS 485W steel plates are limited to a 50 feet/15.24M maximum delivery length from the United States mills.

3. FABRICATION:

3.01 All fabrication must conform to the current edition of the AASHTO ***Guide Specification for Highway Bridge Fabrication with HPS 70W (HPS 485W) Steel***, except as modified herein.

3.02 Restrictions:

3.02.A. Short-term application of heat for purposes of heat curving, heat straightening, or camber and sweep adjustment is limited and not to exceed 1100º F/600° C maximum. All applications of heating must be done by procedures approved by the Engineer or his authorized representative.

3.03 Welding:

3.03.A. All welding must conform to the current edition of the ***AASHTO/ AWS D1.5M/D1.5:2002 Bridge Welding Code***, (referred to hereafter as AWS D1.5) except as modified herein and by the latest edition of the AASHTO ***Guide Specifications for Highway Bridge Fabrication with HPS 70W Steel*** *(referred to hereafter as HPS Fab Guide)*.

3.03.B. Only weld processes and consumables recommended by the *Guide Specifications for Highway Bridge Fabrication with HPS 70W Steel* will be permitted when welding high performance steel. Consumable handling requirements shall be in accordance with AWS D1.5, Sections 12.6.5, 12.6.6 and 12.6.7 and the *HPS Fab Guide.*

3.03.C. The Contractor may request approval of alternate consumables for matching strength welds. The request for approval must include documentation of successful welding in accordance with AWS D1.5, and include diffusible hydrogen tests as described in AWS D1.5, Article 12.6.2 indicating the deposited weld metal has a diffusible hydrogen level equivalent to H4 or less.

3.03.D. All welding procedures must be qualified in accordance with AWS D1.5, Section 5, Qualification.

3.03.E. All procedure qualification tests must be ultrasonically tested in conformance with the requirements of AWS D1.5, Section 6, Part C. Evaluation must be in accordance with AWS D1.5, Table 6.3, Ultrasonic Acceptance – Rejection Criteria – Tensile Stress. Indications found at the interface of the backing bar may be disregarded, regardless of the defect rating.

3.03.F. The procedure qualification test record (PQR) and proposed welding procedure specification (WPS) must be submitted to the Engineer or his authorized representative for review and approval. In general, post weld heat treatment shall not be required. If required by the Contract, or proposed by the Contractor for production or repair welding, such post weld heat treatment must be included in the procedure qualification testing, or qualified by additional PQRs, as appropriate.

3.03.G. Welders and welding operators must be qualified in accordance with the provisions of AWS D1.5.

4. CONSTRUCTION DETAILS:

4.01 All structural steel work, including but not limited to shop drawings, fabrication, inspection, transportation and erection must be done in accordance with the provisions of the ***Standard Specifications***, except as modified by the *HPS Fab Guide.*

4.02 Only fabricators meeting the requirements of the AISC Quality Certification Program, *Major Steel Bridges (Cbr)* with *Fracture Critical Endorsement (F),* or Engineer-approved equal, may fabricate with HPS 70W steel.

4.03 Whenever magnetic particle testing is done, only the yoke technique will be allowed, as described in Section 6.7.6.2 of AWS D1.5, modified to test using alternating current only. The prod technique will not be allowed.

5. METHOD OF MEASUREMENT:

5.01 No measurement shall be taken.

6. BASIS OF PAYMENT:

6.01 The lump sum price shall include the cost of furnishing all labor, materials, and equipment necessary to complete the work, as described on the plans, in this specification and in the applicable sections of the ***Standard Specifications***.

APPENDIX B

ADDITIONAL REFERENCES

Germanson, Tom. *Working with HPS 70W Steel.* Presented at the 77th Annual Meeting of the Transportation Research Board, Washington, DC, January 11-15, 1998.

Nickerson, Robert L. *Tennessee Department of Transportation Martin Creek Bridge, HPS 70W Steel Fabrication and Erection Report and Weld Parameter Study Number 4*. Presented at the HPS Steering Committee Meeting, November 1997.

Nickerson, Robert L. and David Blankenship. *Girder Fabrication Report Number 2 -- Lincoln Steel Company*. Presented at the HPS Steering Committee Meeting, January 1997.

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Wilson, A. D., *Production of High Performance Steels for USA Bridges,* Conference Proceedings Steel Bridge Design and Construction for the New Millennium with Emphasis of High Performance Steel. Baltimore, MD, December 2000.

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Kirsch, Kirby. Report presented at the Regional Seminar in Lincoln, Nebraska, October 6-7, 1997.

Teal, Roy. *HPS 70W – An Owner's Experience.* Presented at the World Bridge Symposium, Chicago, Illinois, 1998.

Teal, Roy. *Summary of High Performance Steel Grade 70W Studies*. Presented at the HPS Steering Committee Meeting, October 1999.

Adonyi, Dr. Yoni. *Evaluation of Tubular (Metal-Core GMAW and FCAW Consumables for Welding HPS-70W.* Presented at the Steering Committee Meeting, October 2002.

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