Steel
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GUIDE SPECIFICATION FOR

HIGHWAY BRIDGE FABRICATION

WITH HPS 100W (HPS 690W) STEEL

for Non-Fracture Critical Applications

November 2012

GUIDE SPECIFICATION FOR HIGHWAY BRIDGE FABRICATION WITH HPS 100W (HPS 690W) STEEL FOR NON-FRACTURE CRITICAL APPLICATIONS

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1. INTRODUCTION

The intent of this *Guide Specification For Highway Bridge Fabrication With HPS 100W (HPS 690W) Steel,* hereafter referred to as the *HPS 100W 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 100W (HPS 690W) steel, referred to hereafter as HPS 100W. The *HPS 100W 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 latest in research and experience with HPS 100W steel may be obtained by contacting the Steel Market Development Institute (SMDI), a business unit of the American Iron and Steel Institute (AISI), at www.smdisteel.org.

HPS 100W is produced in 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—oversee the research and development of High Performance Steel. Appendix A contains a partial list of reports supporting the research findings.

There may be length, width or thickness limitations when using these alternately produced products, based on manufacturer-specific capabilities.

Based on research, certain consumables for the submerged arc welding (SAW), shielded metal arc welding (SMAW), flux cored arc welding (FCAW), and gas metal arc welding (GMAW) processes are included. In addition, the *HPS 100W Fab Guide* recommends specific consumables that have demonstrated 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 H4 and with the use of minimum interpass temperature until the joint is completed**.** It is possible to weld with H8 consumables and the *AASHTO/AWS D1.5M/D1.5:*2010 *Bridge Welding Code* allows the use of welding consumables with an optional designator of H8. The testing performed to support this guide shows that elevated preheat and interpass temperatures are required to weld HPS 100W successfully using consumables with an optional H8 designator. Adequate preheat and interpass temperatures calculated from Annex G or the FCM Preheat and interpass Table 12.5 are satisfactory for H8 consumables.

The consumables being recommended in this guide have an optional designator of H4 or H8 to minimize cracking with normal preheat and interpass temperatures.

As additional welding processes and consumables are evaluated, the *HPS 100W Fab Guide* will be updated to include those recommended for welding HPS 100W steel.

All references made hereafter to AWS D1.5 shall mean the *AASHTO/AWS D1.5M/D1.5:2010 Bridge Welding Code*.

1.1 Fabrication With HPS 100W

The superior toughness of HPS 100W steel, combined with the requirements specified herein, suggest that fabrication in accordance with this *HPS 100W 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 100W components can be successfully completed when work is done in conformance with AWS D1.5 combined with the recommendations of this *HPS 100W Fab Guide*. It is important to keep in mind that the *HPS 100W 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 as an FCM.

2. BASE METAL MATERIAL PROPERTIES

The mechanical property requirements and chemistry can be found in the current ASTM specification under the A709 classification.

HPS 100W 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 100W corrosion resistance is calculated using the Townsend Index 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 100W steel is 7.0.

Like other weathering steels, there is the 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

The mechanical property requirements and chemistry are contained in the current ASTM specification under the A709 classification.

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 100W may be improved when diffusible hydrogen is controlled to a maximum of H_4 based on current studies, but H8 is allowable for fabrication with the correct preheat and interpass temperature controls of Annex g or FCM Table 12.5.

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, and
2.3.6 Heat input.

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 the 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 100W 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 the successful welding of HPS 100W steel. Fabrication in accordance with AWS D1.5, in combination with this *HPS 100W 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. For the SAW process, fluxes received in undamaged hermetically sealed packaging may be used right from the package without baking. Flux received in moisture-resistant packaging shall be baked prior to use (see D1.5, 12.6.6.3). When ordering consumables, and in the case of SAW electrode and flux combination, 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 100W 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 100W steel meets AASHTO Zone 3 requirements, but welds need only meet the site requirements.

3.1 Preheat and Interpass Temperature

Diffusible hydrogen levels up to a maximum of 8 mL/100g must be maintained when the preheat requirements of Table 1 are being used to fabricate part of a bridge structure. This conforms to the requirements of the current AWS D1.5-2010, Table 4.3 for Grades HPS 485W (HPS 70W), 690 (100) and 690W (100W).

The maximum interpass temperature for welding HPS 100W steel is 400˚ F (200˚ C).

3.2 Consumables for Matching Strength Welds

Research has determined the consumables that would be expected to provide sound, crack-free welds using 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 LA100 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 100W Fab Guide* using the minimum preheat and interpass temperatures as listed in Table 1.

Alternate, matching strength, manufacturer-specific electrode/flux combinations will be allowed, providing they conform to AWS electrode/flux Classification F10A4-EXXX-X or

F11A4-EXXX-X with optional supplementary diffusible hydrogen designator H8 or less, as described in AWS A5.23, *Specification for Low-Alloy Steel Electrodes and Fluxes for Submerged Arc Welding*, using the minimum preheat and interpass temperatures listed in Tables 1 and 2. Additionally, flux/electrode classifications with a lower CVN temperature designator are acceptable for welding HPS 100W.

3.2.2 Flux Cored Arc Welding (FCAW)

Matching strength FCAW consumables Tri-Mark TM-115 (AWS Classification E110T5-K3CH4/E110T5-K3MH4 with a minimum heat input of 30 kJ/in), manufactured by Hobart Brothers Company; and Dual Shield T-115 (AWS Classification E110T5-K4C (3/32" dia.) and E111T5-K4M (0.045", 1/16" and 5/64" dia.) with a minimum heat input of 30 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 100W Fab Guide* using the minimum preheat and interpass temperatures as listed in Table 1 or Table 2. 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 SMDI website, www.smdisteel.org, as research and experience progress.

3.2.3 Gas Metal Arc Welding (GMAW)

Matching strength GMAW consumable Tri-Mark Metalloy 110 (AWS Classification E110C-K4), manufactured by the Hobart Brothers Company; Spoolarc 120 (AWS Classification ER120S-1), manufactured by ESAB; and LA-100 (AWS Classification ER100S-G/ER110S-G), 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 100W Fab Guide* using the minimum preheat and interpass temperatures as listed in Table 1 or Table 2. The welding procedure must have a heat input of 30 kJ per inch or higher. 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, pulsed wave current is not allowed.

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

3.2.4 Shielded Metal Arc Welding (SMAW)

Moisture and exposure of shielded metal arc welding electrodes are 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 11018M HZR electrodes with diffusible hydrogen levels of H4 should be used. Use the minimum preheat and interpass temperatures as listed in Table 1 or Table 2. Electrodes must conform to AWS A5.5, *Specification for Low-Alloy Steel Covered Arc Welding Electrodes*.

Handle SMAW electrodes in accordance with Section 12.6.5.

3.2.5 Welding for Hybrid Designs

Consumables listed in the *HPS 70W Fab Guide* for Grade HPS 70W base metal are considered to be matching strength for hybrid designs where HPS 100W base metal is joined to HPS 70W 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 H8.

3.3 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 100W 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 70 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 Table 4. The heat input shown in the table reflects the differences in arc energy for the different processes.

3.4 Heating for Curving, Cambering or Straightening

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

3.5 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 100W 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 100 (690), 100W (690W), HPS 70W (HPS 485W), 50 (345), 50W (345W), HPS 50W or 36 (250) for production welding of Grade 100 or 100W, but not vice versa for the other qualified steels. This same provision should be considered for welding of HPS 100W steel PQR test plate assemblies. This *HPS 100W Fab Guide* recommends the use of HPS 100W for backing whenever possible, and further recommends the substitution of Grades HPS 70W and HPS 50W for HPS 100W 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 any other grades of ASTM A709 when used for backing.

Table 1. HPS 100W (HPS 690W) Minimum Preheat and Interpass Recommendations[1]

Less than 20 mm (3/4 in)	20 mm (3/4 in) to 40 mm (1.5 in)	40 mm (1.5 in) to 65 mm (2.5 in)	Greater than 65 mm (2.5 in)
° C (° F)	° C (° F)	° C (° F)	° C (° F)
10 (50)	50 (125)	80 (175)	110 (225)

[1] The values in this table are based on using welding consumables with an optional H4 designator. These values are identical to D1.5-2010, Table 4.3 for minimum preheat and interpass temperatures for non-fracture critical applications for the current A709 HPS 70W, 100, and 100W materials.

Table 2. HPS 100W (HPS 690W) Minimum and Maximum Preheat and Interpass Recommendations, °C (°F)

	Heat Input kJ/mm (kJ/in)		
Thickness mm (inch)	**1.2 to 1.6 (30 to 40)**	**1.6 to 2.0 (40 to 50)**	**2.0 to 2.8 (50 to 70)**
6 to 10 (¼ to 3/8)	40 – 60 (100 – 150)	________	________
10 to 13 (3/8 to ½)	60 – 160 (150 – 300)	40 - 100 (100 – 200)	________
13 to 20 (1/2 to ¾)	120 - 200 (250 – 400)	100 - 180 (200 – 350)	40 - 120 (100 – 250)
20 to 25 (3/4 to 1)	________	120 - 200 (250 – 400)	120 - 200 (250 – 400)
25 to 50 (1 to 2)	________	________	120 - 200 (250 – 400)
Greater than 50 (>2)	________	________	150 - 240 (300 – 450)

Table 3. HPS 100W (HPS 690W) Filler Metal Recommendations

Process	**Lincoln**	**ESAB**	**Hobart Brothers**
SMAW	Excalibur 11018M MR	Atom Arc T	Hoballoy 11018M
SAW	LA-100/MIL800-HPNi	Spoolarc 120 / OK Flux 10.62	Metalloy 120S
FCAW*		Dual Shield T-115	TM 115
GMAW*	Superarc LA-100	Spoolarc 120	Metalloy 110

*Shielding gas – as recommended by the electrode manufacturer.

Table 4. HPS 100W (HPS 690) Heat Input Recommendations[1]

Process	Net Heat Input		Heat Transfer Efficiency*	Arc Energy**	
	kJ/mm	kJ/in		kJ/mm	kJ/in
SMAW	1.2 - 2.2	30 - 55	0.75	1.6 – 3.0	40 - 74
SAW	1.6 - 2.8	40 - 70	0.95	1.7 – 3.0	42 - 74
FCAW	1.2 - 2.2	30 - 55	0.80	1.5 – 2.8	38 - 69
GMAW	1.2 - 2.2	30 - 55	0.75	1.6 – 3.0	40 - 74

[1] The values in this table are based on using welding consumables with an optional H4 designator.

*Average value based on solid state calorimetry measurements and literature reviews,

η=Net Heat Input/Arc Energy

**Calculated using $[(V \times I) / (S \times 60)] / \eta$

Where V=arc voltage (volts), I=welding current (amps) and S=travel speed (in/min) and η=heat transfer efficiency

HPS 100W Qualification Criteria for Matching Strength Arc Welding Consumables

I. Introduction

High Performance Steel (HPS) has been developed primarily for the bridge girder fabrication industry. HPS is designed to have improved mechanical properties in the heat affected zone (HAZ). The HAZ toughness is improved and the HAZ has superior resistance to cracking. The use of low diffusible hydrogen consumables, H8 or less, are recommended for joining HPS 100W steel. High-quality welds are achieved when the fabricator implements the procedures recommended in the *Guide Specification for Highway Bridge Fabrication with HPS 100W (HPS 690W) Steel*.

A. Scope

The following procedure for qualifying matching strength welding consumables for fabricating HPS 100W is limited to the Submerged Arc Welding (SAW), Shielded Metal Arc Welding (SMAW), Gas Metal Arc Welding (GMAW, both solid and metal cored) and Flux Cored Arc Welding (FCAW) processes.

II. Requirements for SMAW Filler Metal

The SMAW electrode must conform to AWS classification E11018M, as detailed in AWS A5.5/A5.5M-2006, *Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding*. The electrode shall have the optional diffusible hydrogen designator of H4 and the optional moisture-resistance designator R (see Section 3.2.4 of this *HPS 100W Fab Guide*). The electrode shall be packaged in a hermetically sealed container.

III. Requirements for SAW Filler Metal

The SAW electrode and flux combination must conform to AWS classification F10A4-EXXX-X, F11A4-EXXX-X, as detailed in AWS A5.23/A5.23M- 2007, *Specification for Low-Alloy Steel Electrodes and Fluxes for Submerged Arc Welding*. The diffusible hydrogen designator of H2, H4, or H8 is required.

IV. Requirements for FCAW Filler Metal

The FCAW electrode and flux combination must conform to AWS classification E10XT1-X, E10XT5-X, E11XT1-X or E11XT5-X, as detailed in AWS A5.29/A5.29M-2005, *Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding*. The diffusible hydrogen designator of H4 or H8 is required.

V. Requirements for GMAW Filler Metal

The GMAW electrode must conform to AWS classification ER100S-1, E100C-K3, ER110S-1, E110C-K4, ER120S-1, or E120C-K4 as detailed in AWS A5.28/A5.28M-2005, *Specification for Low-Alloy Steel Electrodes for Gas Metal Arc Welding.* At this time, pulsed wave current procedures will not be considered.

VI. Additional Testing Requirements for Filler Metal

The Welding Advisory Group (WAG) Subcommittee of the HPS Steering Committee may, at its option, require additional testing. The all-weld metal tensile specimen may be requested for inspection of the fracture surface for hydrogen damage. The WAG may require a Tekken test, G-BOP, and further diffusible hydrogen testing, subjecting the filler metal to extended high humidity exposure conditions.

VII. Filler Metal Approval

The WAG will list the filler metal as approved after the required information has been submitted and the WAG is satisfied that the results meet the requirements stated in this document. Once approved, the filler metal will be included on the list of approved consumables that can be used to join HPS at the recommended reduced preheat/interpass temperatures.

APPENDIX A

ADDITIONAL REFERENCES

James, Matt & Yost, Lon. *Bridge Code PQR Testing HP 100W Steel MIL800-HPNi & MIL800-H Fluxes Using LA-100 Electrode.* HPS Steering Committee Meeting, October 2005.

Adonyi, Yoni. *Evaluation of Tubular (Metal-Core GMAW and FCAW) Consumables for Welding HPS-100W.* HPS Steering Committee Meeting, October 2007.

Guide Specification for Highway Bridge Fabrication with HPS 70W (HPS 485W) Steel, 2nd Edition. June 2003.

AASHTO/AWS D1.5M/D1.5-2010, *Bridge Welding Code.*

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