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Evaluation Of Properties And Its Enhancement For High Performance Steel

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ABSTRACT:

Structural steel has been used in construction in the United States for more than 100 years. The material and its many products have undergone significant changes since the initial applications. Some of these were prompted by demands for higher strength and improved economies of construction, and many were caused by developments in joining techniques and fabrication. Increasingly complicated and demanding service and other environmental conditions have also been important. A brief review of some early steel developments is presented, but the major focus of the paper is today's requirements for high performance steels, including the properties of tensile strength and stiffness, ductility, toughness, weldability and corrosion resistance. High-strength steels for tailor welded blanks (HSS-TWBs) refer to the stamping blanks or hydroforming tubular blanks that are made from parent blanks of dissimilar materials containing at least one HSS, or from the same HSS but with different thicknesses. HSS-TWBs have received great interest from manufacturing automotive bodies and other structural components where light weight is of primary consideration. The motivation to tailor a blank with dissimilar materials or thicknesses is to better distribute mass/weight and strength in a component, so that required structural functionalities (e.g. strength and safety, crashworthiness) can be better achieved at a reduced cost (by reducing the number of stamping parts and saving trimmed materials)

Key words: High-strength steels, high performance steels, Properties

1.0 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, higher toughness steels to improve the overall quality and fabricability of steels used in bridges in the United States. It was furthermore decided that such steels should be "weathering". By this is meant the ability to perform without painting under normal atmospheric conditions. The timeline of the HPS program is shown in Figure 1. In the United States, the principal steel specifications for bridges are American Society for Testing and Materials (ASTM) A709 and American Association of State and Highway Transportation Officials (AASHTO) M270. Currently, in these specifications, there are steel grades with minimum yield strengths 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 and 100W.

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. The Steering Committee decided that the goal for HPS design would be to develop steels that could meet the most critical requirements of Zone 3.

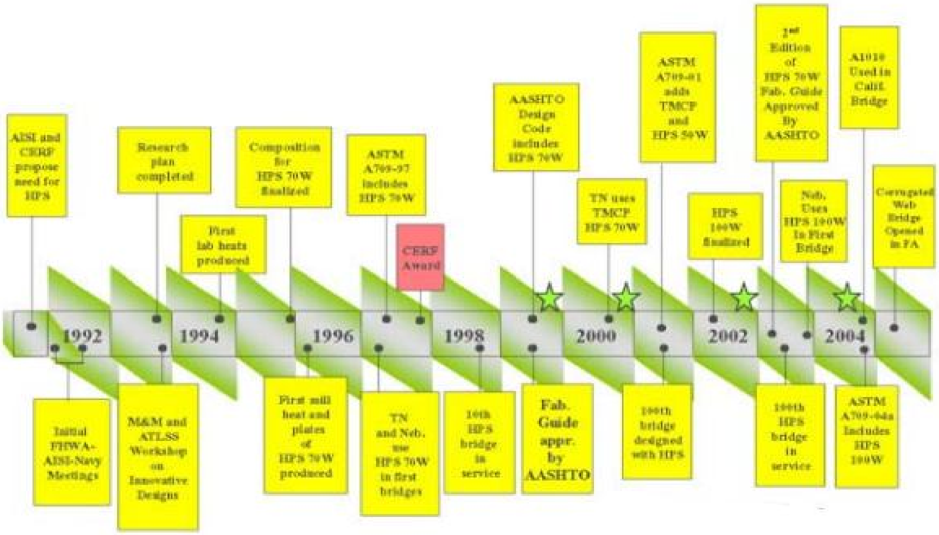


Figure 1: HPS Development Timeline, A Continuing Partnership

2.0 LITERATURE REVIEW

Gang Shi, (2014) High strength steel (HSS) with the nominal yield strength f y≥460 MPa has been applied in numerous modern building and bridge structures all over the world. Steel structures using high strength steel have obvious advantages in structural, architectural, economical, environment protection and energy saving aspects. After a brief introduction of early studies, recent research advances of high strength steel structures in Tsinghua University in China are comprehensively reviewed. Systematic investigations have been carried out on static- and cyclic-loading behavior of high strength steels and their welded connections, residual stress of high strength steel hot-rolled and welded sections, overall and local buckling behavior of high strength steel columns under axial compression, seismic behavior of high strength steel columns under combined bending and compression, bearing and slip resistance of bolted connections with high strength steel slices. The research results show that mechanical behavior of high strength steel structures has been improved much compared with ordinary strength steel structures, so the design methods in current design codes or specifications need be updated to be applicable to high strength steel structures. Therefore, as the chief-editor institute, Tsinghua University has organized 34 institutes including universities, design and research institutes, steel structure fabricators, and steel manufacturers, to codify a new code, i.e. Design Specification of High Strength Steel Structures in China. Based on the above research results, new design methods and calculation formulae applicable to high strength steel structures are incorporated into this design specification. The outline of this specification is discussed in detail in this paper.

Chandan, (2017) Medium carbon low alloy forged steels were investigated (EN18, EN19, EN 24, and EN25) with respect to their mechanical properties by polymer quenching. The effect of polyethylene glycol (PEG) H−(O−CH2−CH2)n−OH as a quenchant was studied by varying polymer concentration (10% and 30%) to investigate the mechanical properties and their metallographic structures. The study was carried out on the medium carbon low alloy forged steels in heat treated condition by hardening in the polymer quenchant. The quenched samples were step tempered at 575^0C and at 220^0C sequentially for 60 min each. Hardness, tensile strength, Charpy impact strength and metallographic were carried out on the untreated and heat treated specimens. The step tempering process of the specimen gives the high strength with high hardenability. The specimen quenched in the polymer solution exhibited the best mechanical properties, viz., as received samples. The mechanical properties are found increased in the polymer quenchant because of the slow and uniform cooling rate of the polymer. The microstructural examination of the specimens were found to have justified reason for the increment recorded in some of the mechanical properties, as it displayed a high proportion of the martensitic phase.

Chrysanthos Maraveas, (2017) High-strength steels (HSS) are produced using special chemical composition or/and manufacturing processes. Both aspects affect their mechanical properties at elevated temperatures and after cooling down, and particularly the residual strength and the ductility of the structural members. As HSS equates the design of lighter structural elements, higher temperatures are developed internally compared to the elements designed with conventional carbon steel. Therefore, the low thickness members, along with the severe effect of high temperature on the mechanical properties of the HSS, constitute to the increased vulnerability of such structures in fire. Moreover, the re-use and reinstatement of these structures are more challenging due to the lower residual mechanical properties of HSS after the cooling down period. This paper presents a review of the available experimental studies of the mechanical properties of HSS at elevated temperatures and after cooling down. The experimental results are collected and compared with the proposed material model (reduction factors) of EN1993–1-2. Based on these comparisons, modified equations describing the effect of elevated temperatures on the mechanical properties of HSS are proposed. Also, the post-fire mechanical properties of HSS are examined. A comprehensive discussion on the effect of influencing parameters, such as manufacturing process, microstructure, loading conditions, maximum temperature, and others is further explored.

3.0 ANALYSIS:

Table 1 Property Requirements for Current HPS Grades

	HPS 50 W Up to 4” (101 mm)	HPS 70W Up to 4” (101 mm)	HPS 100W Up to 1.5” (64 mm)
Yield Strength ksi (MPa) minimum	50 (345)	70 (485)	100 (690)
Ultimate Tensile Strength, ksi (MPa)	70 min. (485)	85-110 (586-760)	110-130 (760-895)
CVN of 35 ft-lb (48J)	+10o F (-12o C)*	-10^{o} F (-23^{o} C)	-30^{o} F (-34^{o} C)
* 30 ft-lb (41J)			

On-going development work continues to demonstrate the improved capability of these HPS grades and identifies other steel compositions with enhanced performance characteristics for bridge applications. Three examples of these improvements will be reviewed

HPS 70W ENHANCEMENTS

HPS 70W is the most widely used of the HPS grades(1). The distribution of yield strength data by plate thickness is shown in Figure 2. The drop-off in yield strength with thickness is apparent. This has led to an increase in manganese content on the ASTM A709 specification for HPS 70W. This is shown in Table 2. For plate over 2.5 in. (64 mm) thick, the Mn maximum has been increased from 1.35% to 1.50%. This should facilitate meeting minimum yield strength requirements without having to re-heat treat plates. ASTM A709-04 versions going forward reflect this change

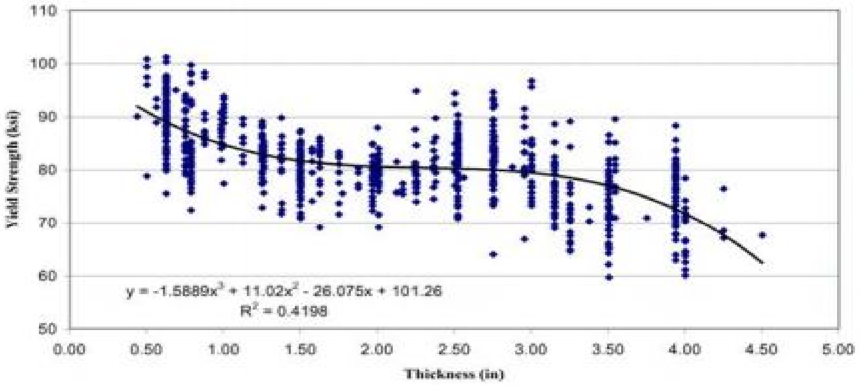


Figure 2: HPS 70W Yield Strength vs. Thickness

Table 2 Chemistry for HPS 70W – Specification Modification

HPS 70W(1)		C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V
	Min	-	1.10	-	-	.30	.25	.25	.45	.02	.04
	Max	.11	1.35(2)	.020	.006	.50	.40	.40	.70	.08	.08

1) Calcium treated for inclusion shape control, also requires .010-.040 A1
2) Mn max. To increase to 1.50 for plate over 2.5” thick

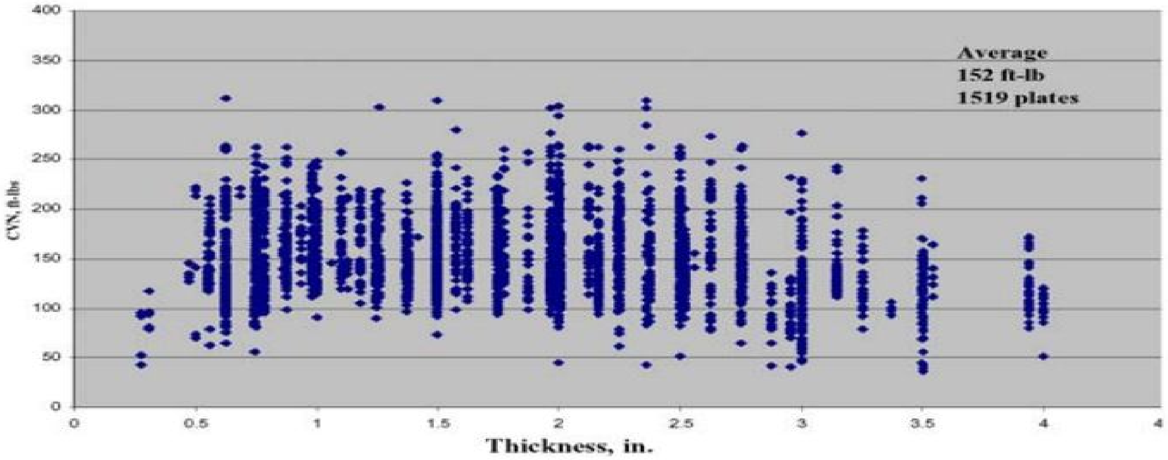


Figure 3: HPS 70W Q&T, -10F CVN Data vs. Thickness

The Charpy-V-Notch (CVN) impact properties for HPS 70W have been consistently well above even the more demanding fracture critical requirements of 35 ft-lb @-10° F (48J @ -23C). This is shown in Figure 3. According to steel specification requirements, if the yield strength is over 85 ksi (586 MPa), the CVN test temperature is dropped to –25° F (- 32C). Even at this lower test temperature and with a higher strength level, the minimum CVN requirement is met consistently, as shown in Figure 6. The data shown in Figures 5 and 6 represent quenched and tempered production. Similar CVN results are achieved for up to 2 in. (51 mm) thick plate produced by ThermalMechanical-Controlled-Processing (TMCP). This suggests that for special applications, more rigorous CVN criteria may be considered. For example, for special fracture-critical applications, a minimum CVN level of 50 ft-lb may be appropriate and even a lower test temperature may be utilized. These issues are being considered for future upgrades of the specification, particularly for fracture-critical applications.

THICKER HPS 100W

The HPS 100W grade is the most recent HPS development. The chemistry that was developed used the U. S. Navy's experience with Cu-Ni alloy steels as a basis. The chemistry shown in Figure 4 was developed to meet strength and toughness properties to 2.5 in. (64 mm) thick. There was interest in establishing whether this chemistry would be effective to 4 in. (100 mm) thickness. Two plates 3 and 4 in. (76 and 101 mm) thick were rolled and quenched and tempered. The results of the evaluation of these two plates together with all available HPS 100W production results is summarized in Figures 8 and 9. All of the results passed minimum A709 requirements, however, the plates 2.5 in. and thinner passed CVN toughness requirements by a wider margin. Re-heat treatment of these plates is being undertaken.

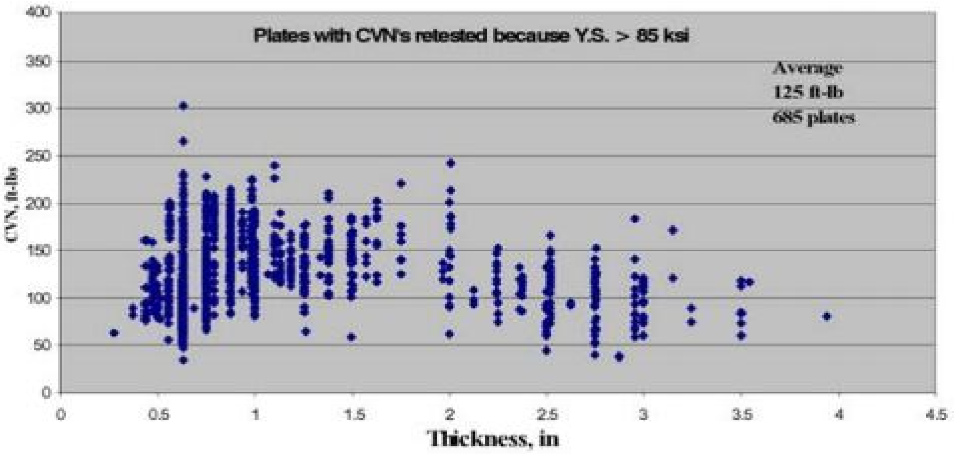


Figure 4: HPS 70W Q&T, -25FCVN Data vs. Thickness

To achieve higher toughness in thicker plates would require increasing the nickel content. Already has analogous grades for 100 ksi (690 MPa) yield strength applications. One of their existing chemistries is shown in table 3. The requirements are at –120o F (-84C), significantly beyond bridge applications. The chemistry in Table 3 is intended for up to 2 in. (51 mm) plate for the Navy. The HPS Steel Advisory Committee is considering evaluation of this chemistry for bridge applications to 4 in. (101 mm) thick.

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

Traditional 100W(2,3)		**C**	**Mn**	**P**	**S**	**Si**	**Cu**	**Ni**	**Cr**	**Mo**	**V**
Min		.10	.60	-	-	.15	.15	.25	.70	.40	.03
Max		.20	1.00	.035	.035	.35	.50	1.00	.65	.60	.08
HPS 100W(1,2,4)											
Min		-	.95	-	-	.15	.90	.65	.40	.40	.04
Max		.08	1.50	.015	.006	.35	1.20	.90	.65	.65	.08
HSLA 100(1,5)											
Navy grade	Min	-	.75	-	-	-	1.00	2.50	.45	.45	-
	Max	.06	1.15	.020	.004	.40	1.30	3.00	.75	.60	-

1) Calcium treated for inclusion shape control
2) 2-1/2 (65mm) max. Thickness
3) Contains .001B
4) Contains .01/.03 Nb, .02/05 Al and .015 max. N

5) HSLA-100 Composition 2 contains .02/.06 Nb, Min. 0.015 Total A*l*

A1010, 12% CHROMIUM STEEL:

ASTM A1010 is a 12% chromium structural steel with superior corrosion resistance. A1010 is currently widely used in aggressive structural applications such as coal rail cars and coal processing equipment in thicknesses to 0.5 in. (12 mm). Because of A1010’s superior corrosion resistance, it is also being considered for challenging bridge applications. Data on thickness to 4 in. (101 mm) thick are now available.

The chemistry of A1010 is shown in Figure 5. If used in bridge applications, a lower sulfur requirement would be added for improved CVN toughness. Laboratory corrosion testing to the SAE 52334 standard has shown A1010 to perform in a superior fashion in a wet/dry saltwater environment when compared to weathering or galvanized specimens. This is summarized in Figure 6. Also, long-term exposure to seaside locations has shown it to perform significantly better than a variety of weathering steel. Because of the superior corrosion resistance, A1010 was used in Colusa County, California, cellular box girder bridge using 0.16 in. (4 mm) thick product as shown.

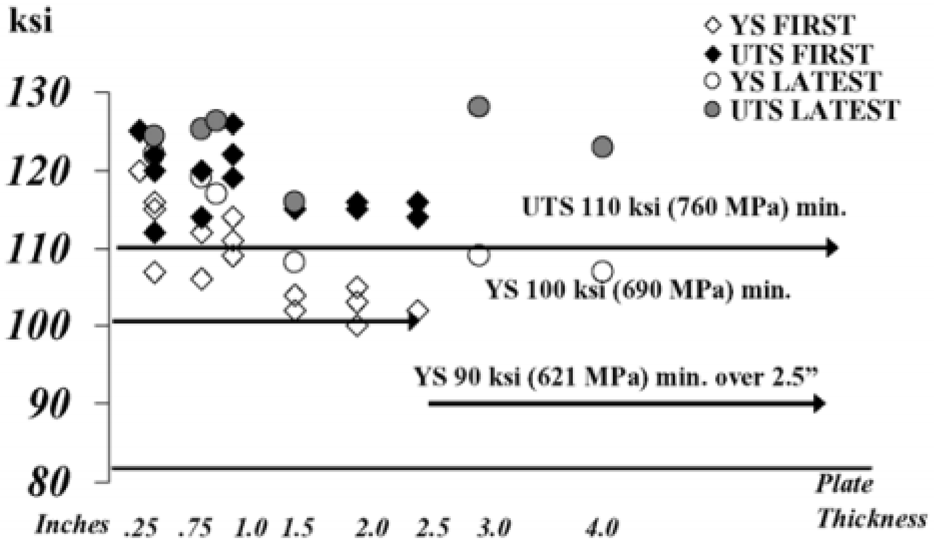


Figure 5: Tensile Properties, HPS 100W Production Heats

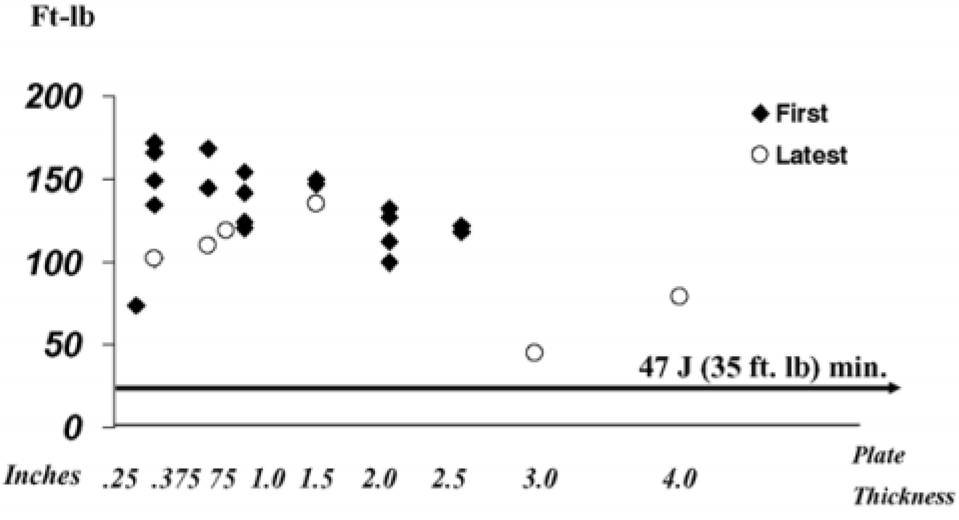
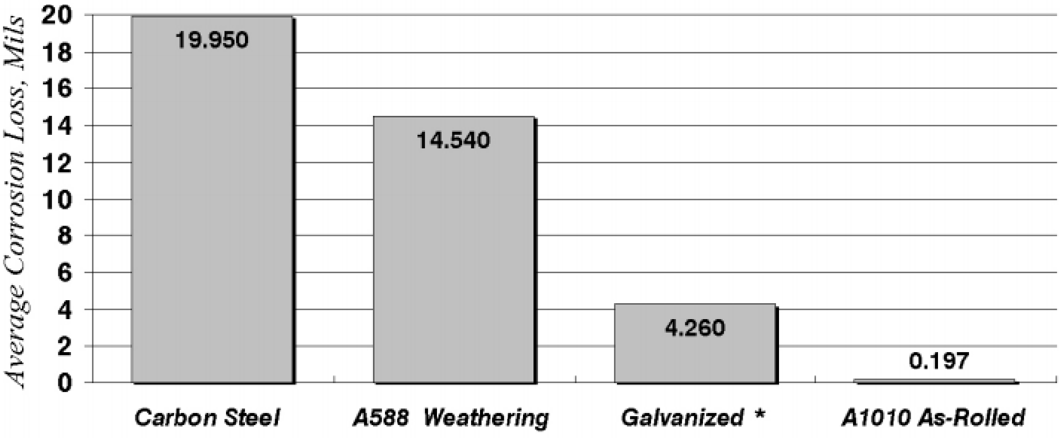


Figure 6: CVN Energy @ -34°C (-30°), HPS 100W Production Heats

Table 4 Chemistry of Duracorr & ASTM A1010

ASTM		C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V
A1010(1)	Min	-	-	-	-	-	-	-	10.5	-	-
	Max	.03	1.50	.040	.030(2)	1.00	-	1.50	12.5	-	-

1) .030 max. N
2) .005 max for bridge applications



* Coated carbon steels

Figure 7: Corrosion Performance in SAE J234 Test

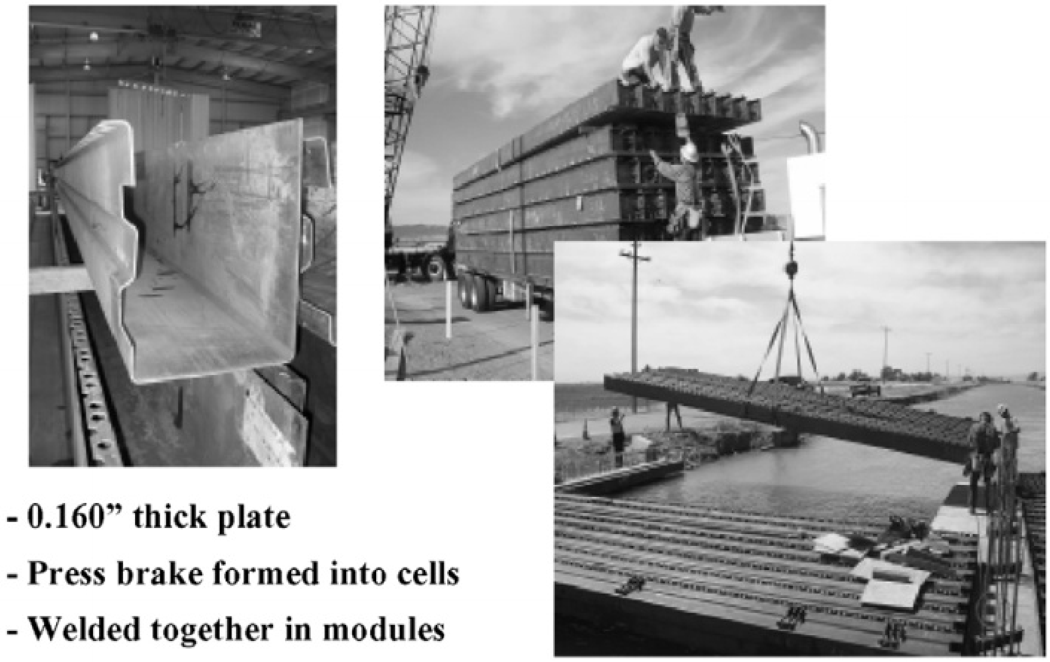


Figure 8: California A1010 Bridge

For traditional bridge applications, properties have been developed for thicker sections as shown in Figures 7 and 8. Our evaluations have established the following production capabilities for this grade.

	Thickness, in. (mm)	
Yield Strength min. Ksi (MPa)	To 1.5 (38)	To 4 (101)
50 (345)	HR&	Q&T
70 (485)	Q&T	Q&T to 2.5 in. (64 mm)

HR&T: hot rolled and tempered; Q&T: quenched and tempered

The availability of A1010 in these sizes and strength levels make it an alternative steel for challenging bridge applications, where full life cycle costs are a consideration. Currently, A1010 is roughly double the cost of A709 Grade 50W weathering steel.

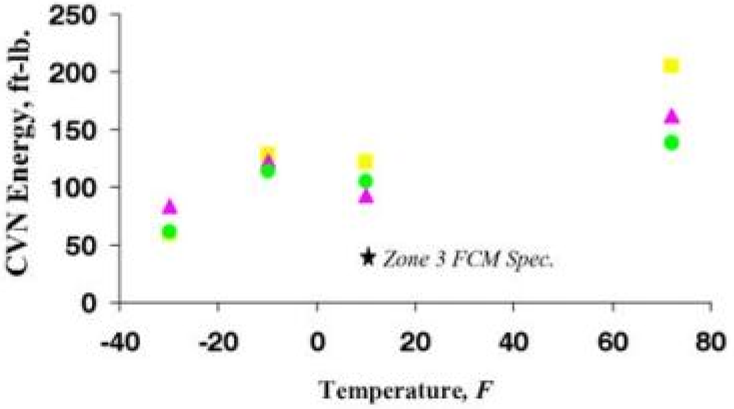


Figure 9: A1010 CVN Properties, Three Grade 50 Plates; Rolled & Tempered 1" and 1.5" Thick

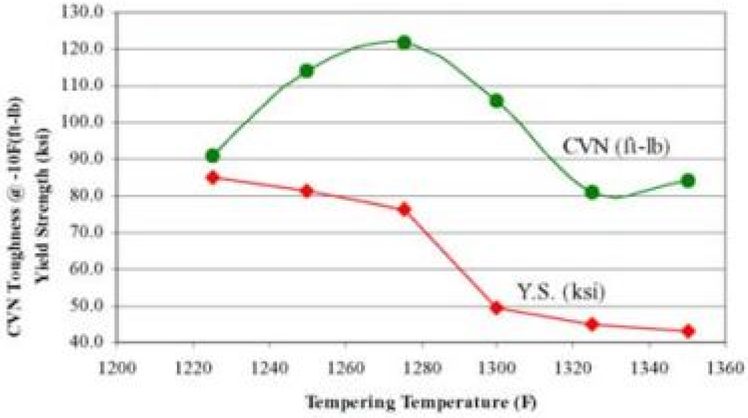


Figure 10: Yile Strength and CVN Toughness vs. Tempering Temperature 2.5" A1010

4.0 CONCLUSIONS

Welded high strength steels indicate that the general performance of the high strength steels is as good as the medium strength steels. The only condition where poor performance was found was with H2S but medium strength steels also show similar poor performance. Weld improvement techniques show promise but require data for typical offshore conditions. In all areas more data are required before confident predictions of the fatigue performance of high strength steels can be made. At the present time producing test data for candidate high strength steels still appears to be the best approach.

1. The HPS 70W has excellent CVN toughness properties that would allow more rigorous toughness criteria for challenging applications. 2. HPS 100W thicker than 2.5 in. (64 mm) can be produced, but for superior CVN toughness levels, an improved higher nickel containing Navy grade will be evaluated. 3. A1010 has excellent corrosion resistance and is available in typical plate sizes in 50 ksi (345 MPa) and 70 (485) strength levels.

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