Improvements to High Performance Steels

by

Alexander Wilson
Manager, Customer Technical Service
Mittal Steel USA,

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.

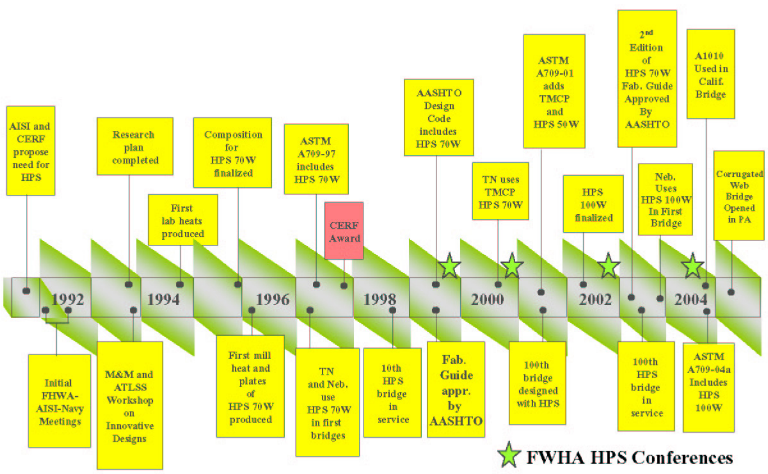

Figure 1: HPS Development Timeline, A Continuing Partnership

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 2
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)	+10°F (-12°C)*	-10°F (-23°C)	-30°F (-34°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 3. 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 Figure 4. 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[2].

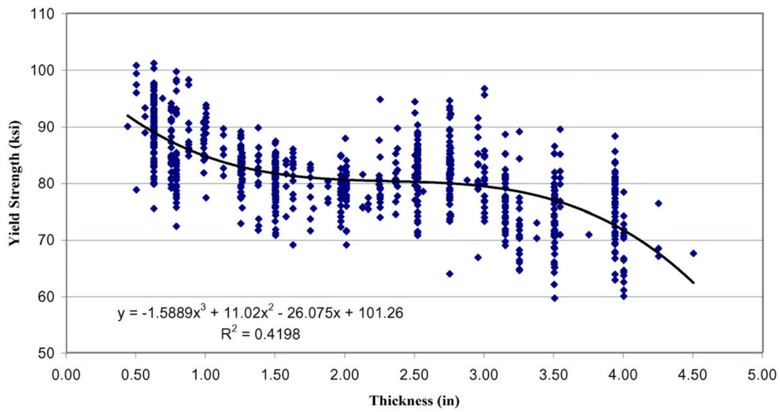

Figure 3: HPS 70W Yield Strength vs. Thickness

		C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V
HPS 70W (1)	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 Al and .015 N max.

(2) Mn max. to increase to 1.50 for plate over 2.5" thick

Figure 4: Chemistry for HPS 70W – Specification Modification

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 5. 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 Thermal-Mechanical-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.

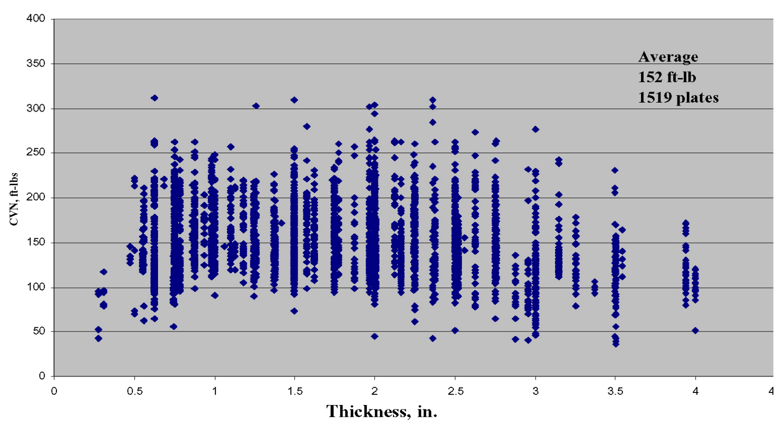

Figure 5: HPS 70W Q&T, -10F CVN Data vs. Thickness

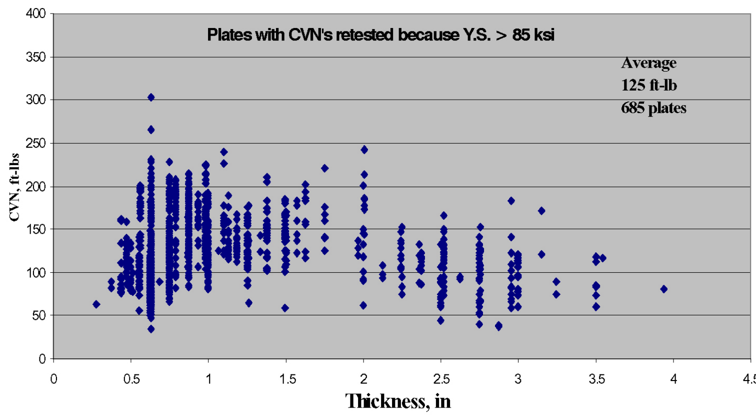

Figure 6: HPS 70W Q&T, -25FCVN Data vs. Thickness

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[3]. The chemistry shown in Figure 7 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.

To achieve higher toughness in thicker plates would require increasing the nickel content. The U. S. Navy already has analogous grades for 100 ksi (690 MPa) yield strength applications[4]. One of their existing chemistries is shown in Figure 7. The U. S. Navy's CVN requirements are at –120°F (-84C), significantly beyond bridge applications. The chemistry in Figure 7 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.

		C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V
Traditional 100W (2, 3)											
Min.		.10	.60	-	-	.15	.15	.70	.40	.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" (65 mm) 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 Al

Figure 7: Comparison of Chemistries for Traditional and HPS Versions of 100W

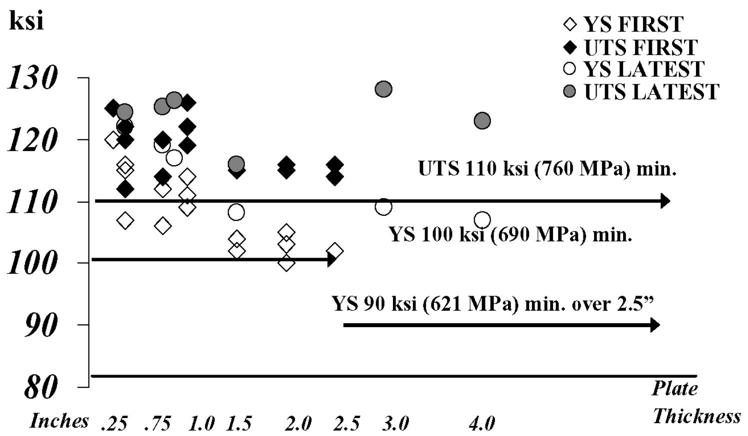

Figure 8: Tensile Properties, HPS 100W Production Heats

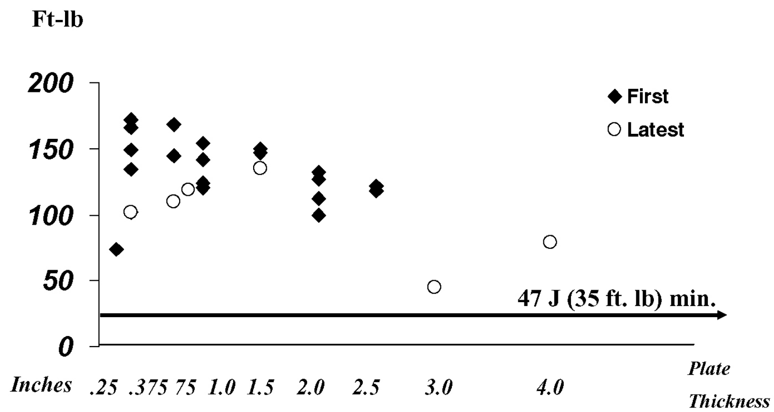

Figure 9: CVN Energy @ -34°C (-30°), HPS 100W Production Heats

A1010, 12% CHROMIUM STEEL

ASTM A1010 (Mittal Steel USA “Duracorr®”) is a 12% chromium structural steel with superior corrosion resistance [5,6]. 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 10. 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 salt-water environment when compared to weathering or galvanized specimens. This is summarized in Figure 11. Also, long-term exposure to seaside locations has shown it to perform significantly better than a variety of weathering steels, as noted in Figure 12. 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 in Figure 13.

	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V
ASTM 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

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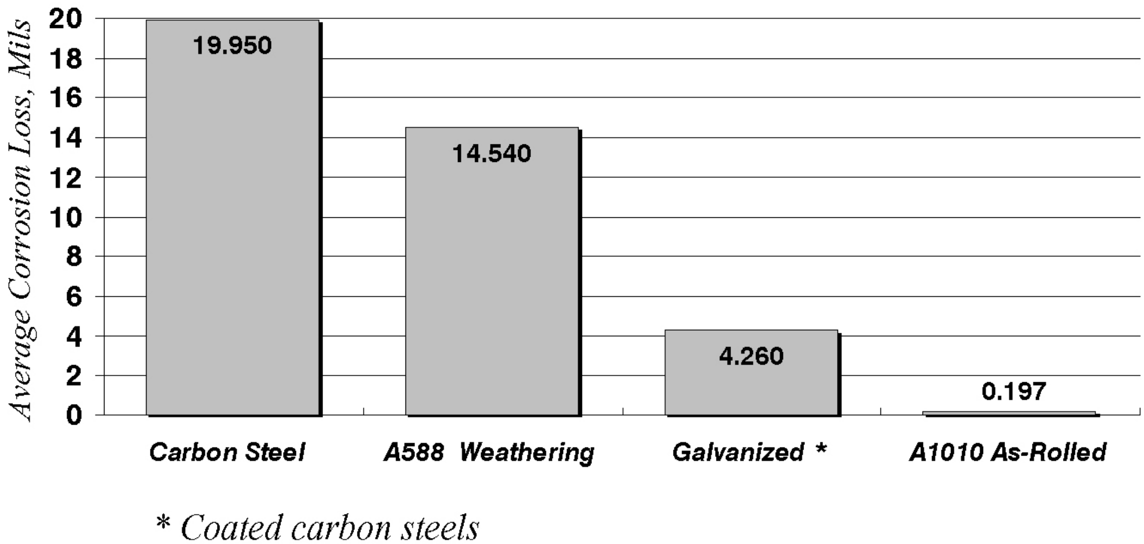
Figure 10: Chemistry of Duracorr® & ASTM A1010



* Coated carbon steels

(1) salt, wet/dry, 8-week test

Figure 11: Corrosion Performance in SAE J234 Test [1]

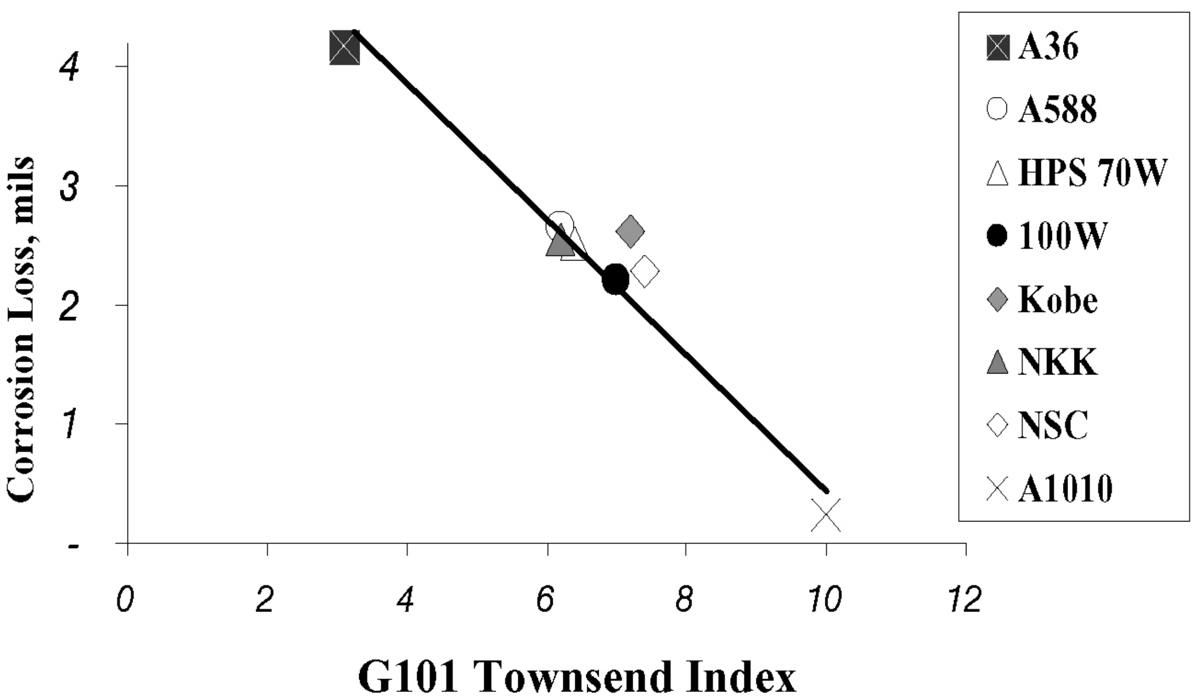


Figure 12: Thickness Loss After 4 Years, Kure Beach 25m Location

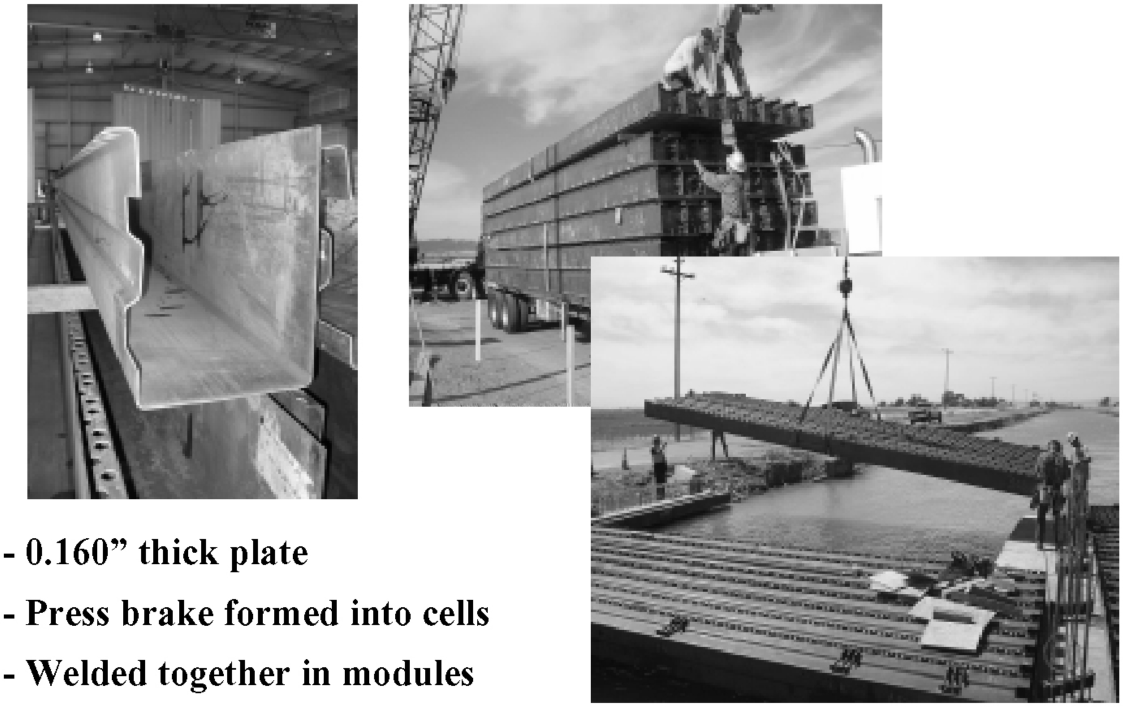


Figure 13: California A1010 Bridge

For traditional bridge applications, properties have been developed for thicker sections as shown in Figures 14 and 15. Our evaluations have established the following production capabilities for this grade.

Yield Strength min. Ksi (MPa)	Thickness, in. (mm) To 1.5 (38)	Thickness, in. (mm) To 4 (101)
50 (345)	HR&T	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.

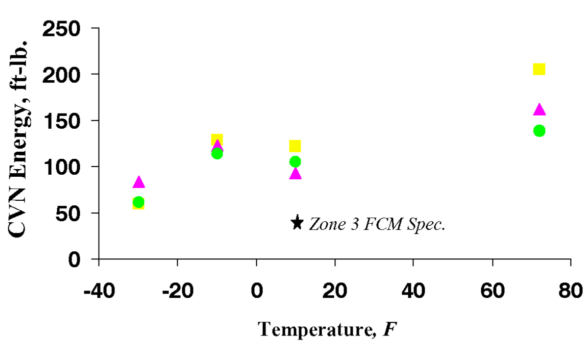


Figure 14: A1010 CVN Properties, Three Grade 50 Plates; Rolled & Tempered 1" and 1.5" Thick

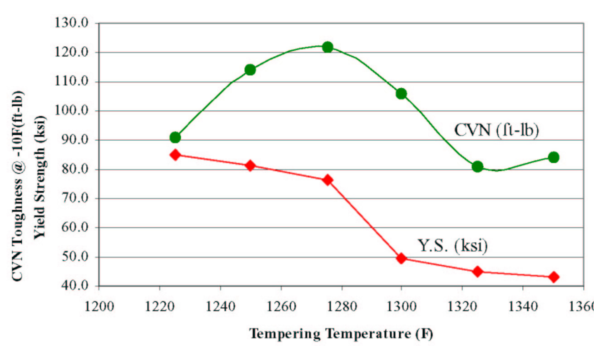


Figure 15: Yile Strength and CVN Toughness vs. Tempering Temperature 2.5" A1010

CONCLUSIONS

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.

ACKNOWLEDGEMENTS

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