Stainless Steel for Accelerated Bridge Construction

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ABSTRACT

ASTM A1010 is a 12% chromium stainless plate steel used in corrosive structural applications because of its superior performance when compared to weathering or galvanized steels. A1010 can be produced at 50 ksi minimum yield strengths to 4 inches thick and to 70 ksi to 2.5 inches thick. Recent production properties and corrosion results will be reviewed. The first use of A1010 in a bridge application was in a multi-cell box girder (MCBG) design for prefabricated bridges recently completed in Colusa County, California. The presentation will describe the MCBG concept, will detail the fabrication of the modules, and will illustrate the bridge erection process with brief video clips and photographs.

INTRODUCTION

Steel bridges represent some of the world's greatest engineering achievements. An important design and maintenance factor for bridges made of exposed steel is how the steel corrodes. In recent years, "weathering" steels such as ASTM A709 50W, HPS 50W and HPS 70W have been chosen for more than half of the newly built bridges in the United States because in most cases the weathering steels undergo significantly lower atmospheric corrosion rates than conventional bridge steels. Weathering steels generally do not need to be painted, thereby minimizing maintenance costs for owners. However, like conventional carbon steel a corrosion allowance must be added to the steel thickness to account for gradual oxidation of a weathering steel. To get rid of the need for a corrosion allowance, metallurgists have developed a new low cost structural stainless steel designated ASTM A1010. By selecting A1010 steel for bridge construction thinner steel can be used, thereby reducing the weight of the bridge. The lighter weight bridge has many collateral benefits that may allow the contractor to accelerate the construction process, that is, to "get in and get out" faster. And using A1010 makes it possible to essentially eliminate steel maintenance, i.e. to "stay out" for the life of the bridge.

ASTM A1010 STEEL

ASTM A1010 (Mittal Steel USA's "Duracorr®") is a 12% chromium structural steel with superior corrosion resistance (1,2). A1010 is widely used in thickness from 0.125-in. to 0.5-in. (3 to 12 mm) for structures subjected to aggressive service conditions such as coal rail cars and coal processing equipment. Because of A1010's superior corrosion resistance, it is also a candidate for challenging bridge applications. The steel can meet the strength and impact properties of AASHTO M270 Grades 50W and HPS 50W up to a thickness of 4-in. (102 mm), making it an attractive steel for conventional plate girder bridges.

The composition of A1010 is shown in Table 1. When used in bridge applications, a lower sulfur requirement is added for improved toughness. The excellent impact toughness of

Table 1
Composition of Duracorr® and ASTM A1010

	C	Mn	P	S	Si	Ni	Cr
Min.	-	-	-	-	-	-	10.5
Max.	0.03	1.50	0.040	0.030*	1.00	1.50	12.5
* 0.005 max. for bridge applications							

Duracorr® is illustrated in Figure 1. The data shown are for four plates between 1-inch and 2.5-inches thick, tempered to meet 50 ksi minimum yield strength. Thinner Duracorr® plates

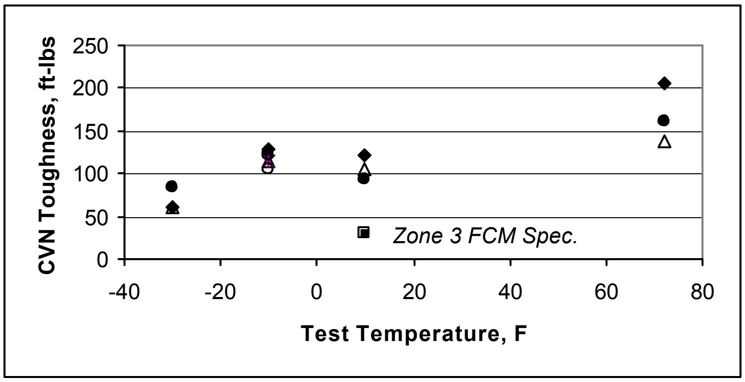

Figure 1. Charpy V-Notch (CVN) impact toughness of 1-inch through 2.5-inch thick Duracorr® A1010 plates.

exhibit similar Charpy impact toughness. In particular, the impact toughness of the A1010 steel exceeds by a comfortable margin the most severe (Zone 3) requirements for fracture critical members as shown in Figure 1.

Laboratory corrosion testing in a wet/dry salt-water environment to the SAE J2334 standard has shown A1010 to perform in a superior fashion compared to weathering steel or galvanized specimens. This is summarized in Figure 2.

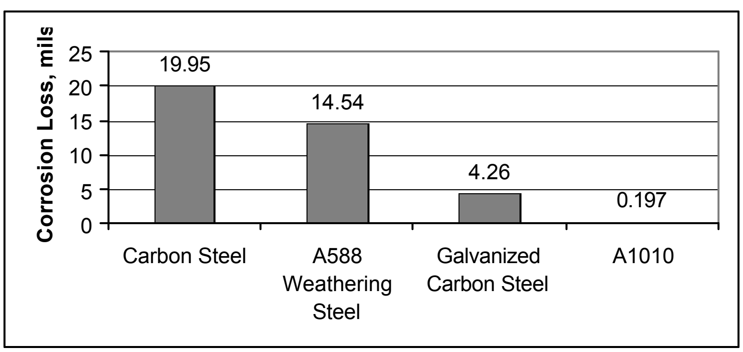

Figure 2. Corrosion performance in SAE J2334 test consisting of alternating wet/dry cycles with salt for 8 weeks.

Also, long-term exposure at seaside locations demonstrates that A1010 performs significantly better than a variety of weathering steels, as shown in Figure 3.

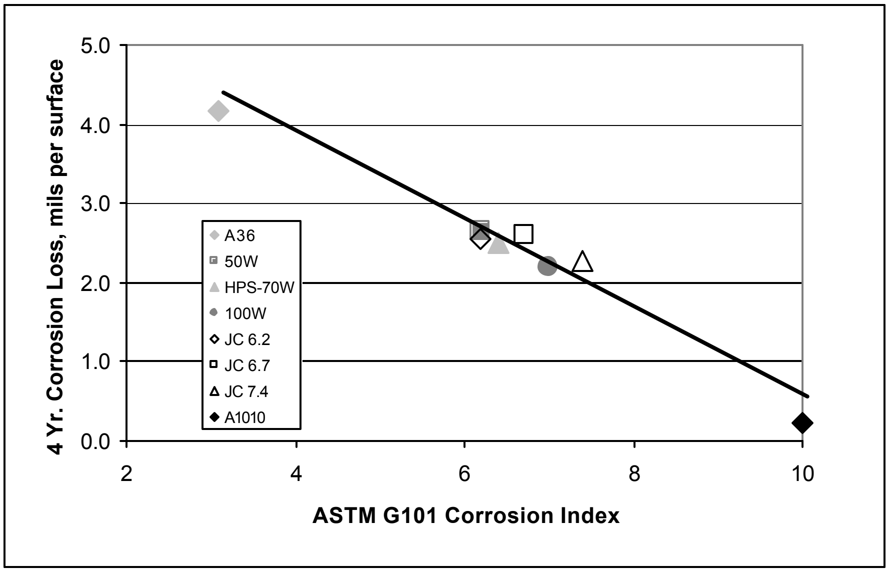

Figure 3. Corrosion loss after 4 years' exposure at Ocean Front lot at Kure Beach, NC for A36 carbon steel, a group of weathering steels, and A1010.

Although A1010 is formally classified as a stainless steel, it has the same appearance and it can be handled like conventional bridge steels. For example, it is magnetic, it has a dull gray mill scale surface, and it bends and machines similarly to other 50 ksi yield strength carbon and weathering steels. The significant fabricating differences between A1010 and conventional bridge steels relate to thermal cutting and welding. The high chromium content of A1010 renders it more difficult to oxy-fuel cut; plasma cutting is the recommended thermal cutting procedure. It is also necessary to employ a stainless steel welding consumable such as E309L and relatively low heat input welds are recommended to assure good heat affected zone toughness with no loss of corrosion behavior.

MULTI-CELL BRIDGE GIRDER

The multi-cell bridge girder (MCBG) was developed in the 1990's specifically for short span bridges 20 to 100 feet (6 to 30 m) long. The concept is to manufacture standardized 8-foot (2.4 m) wide modules in a plant, transport them to the site, place them on prepared supports, and pour a cast-in-place composite concrete deck and end diaphragms. There are significant economies possible by manufacturing the steel structure in a factory setting. And an MCBG bridge can be erected very rapidly after the supports are prepared: The contractor can "get in and get out" quickly.

Proof-of-concept was demonstrated in 1996 when a 40-ft (12 m) long MCBG module was load tested at UC San Diego. This module was made with 5/16-inch (8 mm) thick A36 carbon steel and it was subjected to 2 million fatigue cycles of HS-20 loading. The testing confirmed the design stress calculations. Initial yielding occurred at 3.0 times the design load. Testing was halted at 5 times the design load without failure at which time the maximum stroke of the loading system was reached. Neither the top steel nor slab reinforcement reached their respective yield levels. Based on this successful test, Caltrans approved (3) the MCBG design for "use on [California] highways where the AASHTO specifications govern the design."

The basic elements of the MCBG are illustrated in Figure 4. Steel plates of the design length are roll formed or press brake formed into a modified "C" shape. The dimensions of the vertical "web" and the horizontal "flanges" are based on the bridge design but are typically of the order of 15-inches (380 mm). In this particular example, a channel is formed as part of the

top surface, and a vertical “lip” is also formed. Eight such sections are partially inserted into one another and longitudinal FCAW welds are made to securely attach adjoining “cells”.

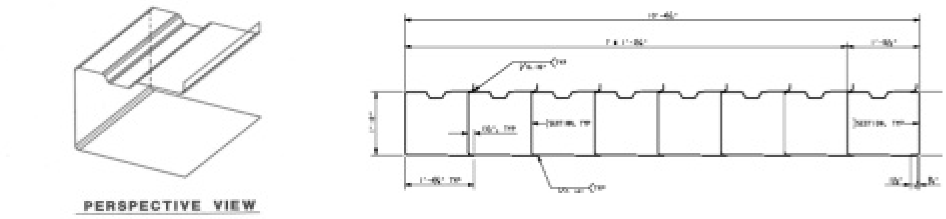

Figure 4. Perspective view of formed steel sections and eight such sections inserted into one another to form an MCBG module.

Diaphragms are tack welded into both ends of each cell, thereby completing one MCBG module as illustrated in Figure 5.

COLUSA COUNTY PROJECT

By using A1010 steel instead of carbon or weathering steel for an MCBG bridge, the thickness of the steel can be reduced from 5/16-inch (8 mm) to 0.160-inch (4 mm) and thereby the weight can be halved. To demonstrate the light-weight A1010 MCBG concept, in 2001 Colusa County developed and submitted a grant proposal to Caltrans for the FHWA’s Innovative Bridge Research and Construction (IBRC) program. FHWA accepted the proposal in 2002 and awarded Caltrans $400,000 for the cost of design and construction of the innovative items.

Figure 5. Fabricated MCBG modules on the factory floor.

The demonstration bridge is on Fairview Road over the Glenn-Colusa Main Canal near the town of Williams in Colusa County, California. The bridge owner is Colusa County, Benco Bridges was the contractor, and the fabricator was Stoltz Metals of Richmond, California. The MCBG bridge consists of two 35-foot (10.7 m) long spans between abutments and a centrally located pier. The bridge is 72-feet 6-inches (22.1 m) long by 31-feet 6-inches (9.6 m) wide. It is designed for HS20-44 live loading and seismic loading of magnitude 7.0 with a peak acceleration of 0.50g. Design issues that had to be addressed included the shear connection between the cast-in-place slab and the steel modules. The solution was developed in Germany and tested at Prague in the Czech Republic. Another design challenge was the steel connection at the C-I-P bent cap; the joint design was verified by a test at Brno, Czech Republic. Because existing codes do not cover the distribution of loads on a MCBG bridge, finite element modeling was carried out to estimate loads and deflections.

The structural material is ASTM A1010 Grade 50 steel with a minimum yield strength of 50,000 psi. The steel, donated to the project by a Mittal Steel predecessor company, was in the form of thin 0.160-inch (4 mm) plates. These were water-jet cut to provide holes and end

details, then the plates were press brake formed into 48 “C”-shaped sections as illustrated in Figure 4. A module was made by stitch welding eight adjoining sections on ~18-inch (~450 mm) centers along the 35-foot (10.6 m) length. Final FCAW welding with E309L wire was continuous from one end to the other; two welds were made simultaneously on opposite “sides” of the module to minimize distortion. Final shop fabrication included installing diaphragms at the ends of each “cell” made from A1010 steel. Low carbon steel shear studs were stud-welded to the A1010 without difficulty. Attachments were also welded to provide for rail post connections.

The six modules, each weighing about 7,600 pounds (3.5 tonnes) were loaded on one truck for shipment to the job site. A light-weight crane lifted the modules one at a time—as shown

Figure 6. Placement of MCBG modules on demonstration bridge.

in Figure 6—and placed them on the supports; the entire process took only 20 minutes per module. Reinforcement was run and final preparation for pouring the concrete deck required several days. The deck was poured sequentially to assure proper stresses. Finally, the carbon steel thrie beam barrier posts were attached to the bridge and the guard rails assembled. Final grading completed construction of the bridge, Figure 7.

Figure 7. Sequential deck pour and finished MCGB bridge.

As part of the IBRC proposal, strain gages were installed in various locations on the bridge. Deflections and stresses were measured shortly after the bridge was opened to traffic. Figure 8 shows the location of some of the strain gages and the load test conditions. The measured stresses and deflections were in good agreement with the design assumptions. The MCBG structure behaved elastically even under the heaviest loads.

SUMMARY

The availability of ASTM A1010 in a variety of sizes and strength levels makes it an alternative steel for challenging bridge applications where full life cycle costs are a consideration. Currently, A1010 is roughly double the price of A709 Grade 50W weathering steel. However, because of its excellent corrosion resistance, thin plates of A1010 can replace thicker plates of the A709 grades. Such a change reduces the weight of steel required, and the weight of the structure. A cascading effect of lower costs may accompany the lighter weight of the steel bridge.

Figure 8. Strain gages attached to MCBG bridge and trucks for load tests.

Employing A1010 stainless steel in bridge construction also reduces the need for maintenance to a minimum. A1010 bridges may be painted; paint adheres very well to the tight mill oxide surface of the steel. Alternatively—as in the case of the demonstration MCBG bridge—the steel may be left bare. In this case, the gray color of the A1010 will change over several years to a light red/brown color.

The MCBG concept as realized with ASTM A1010 was shown to be a useful way of prefabricating light-weight but stiff bridge modules. Assembled onto supports and with the addition of an integral deck, an MCBG bridge can be rapidly erected. The MCBG design make accelerated bridge construction possible: The contractor can "get in and get out" quickly.

Some environmental conditions are sufficiently severe that weathering steels are not recommended for bridge construction. These include microclimates where there are high times of wetness and where there is a heavy salt load. Laboratory and exposure testing have demonstrated that A1010 performs significantly better than weathering steels and galvanized in such environments. Thus, A1010 is an excellent candidate for low-maintenance steel bridges exposed to the most severe environmental conditions. A bridge built with A1010 steel enables the "stay out" philosophy of bridge repair to be realized.

ACKNOWLEDGEMENTS

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