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STATE HIGHWAY ADMINISTRATION

Research Report

STAINLESS STEEL PRESTRESSING STRANDS AND BARS FOR USE IN PRESTRESSED CONCRETE GIRDERS AND SLABS

MORGAN STATE UNIVERSITY
DEPARTMENT OF CIVIL ENGINEERING

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16. Abstract

Corrosion decay on structures has continued to be a challenge in the scientific and engineering communities, where significant federal and state funds have been spent towards replacement or rehabilitation of bridges that were damaged by corrosion deterioration. In Maryland, a great portion of its yearly bridge funding allocation is spent on performing repairs and rehabilitations on its aging bridge inventory. In an effort to reverse this trend, SHA has monitored problematic design practices and adjusted present designs to avoid future maintenance issues. One area that has been particularly problematic for SHA is the deterioration of prestressed steel strands in prestressed concrete beams and girders. In fact, in recent years, SHA has performed emergency span replacements on two different bridges because the strands had deteriorated to such an extent that serious safety concerns were exposed. One tactic SHA has used to remedy this issue has been to increase the concrete cover requirements beyond code requirements to help prevent the onset of deterioration. This will help, but comes at a price. The strands are less effective and more strands are often required. Therefore, this research consisted of gathering and synthesizing information on how others have addressed this issue, as it relates to the deployment of other materials that can be used to provide durable corrosion protection and prevention of premature spalling or corrosion-induced cracking. To assess the use of stainless steel and other materials, a survey was conducted and disseminated to contractors, personnel at various departments of transportation, and construction industry personnel. This study presents a summary of various projects that have used corrosion-resistant rebar (CRR), a summary of what other states are doing to address this issue, and results from the survey of how various states are addressing the issue of corrosion decay on structures.

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Acronyms and Abbreviations

CRR	Corrosion Resistant Rebar
DOT	Department of Transportation
ECR	Epoxy-Coated Rebar
FRP	Fiber Reinforced Polymer
FHWA	Federal Highway Administration
LCCA	Life-Cycle Cost Analysis
MMFX2	Microcomposite Multistructural Formable
SHA	Maryland State Highway Administration

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EXECUTIVE SUMMARY

This final report synthesizes critical information about stainless steel and other remedies that have been used to replace corroded prestressing steel strands and bars or prolong the corrosion rate. Various cases studies and applications of these alternate materials to conventional steel are presented and summarized herein. Questions still remain unanswered for the overall long-term durability of these materials although preliminary numbers indicate a potential savings over the life-cycle of a structure if the materials are purchased in large quantities. Moreover, companies that manufacture and sell these materials have been identified in this report.

To assess the current state-of-the-practice and art of using alternate materials (often referred to as corrosion resistant rebar, CRR) and strategies to minimize the issue of corrosion, a survey was created and disseminated to various DOT personnel, precasters and mill representatives. From the survey, several questions needed to be addressed in order to meet the ***main objective*** of determining the feasibility and accessibility of stainless steel prestressing strands and bars as materials to be considered for use in prestressed concrete girders and slabs such as:

- What is the availability of the stainless strands?
- Can they be installed the same way? Same equipment?
- Is the strength and ductility the same?
- Would it make sense from a life-cycle cost perspective?
- Would it reduce current clear cover requirements that exceed AASHTO?
- Could the material be used in combination with regular prestressed strands?
- Is the use of stainless strands more economical than the use of hyper-dense impermeable concrete mixes such as silica fume blends?

The results to these questions are compiled in this final report. Also included in this final report are life-cycle cost analysis studies that have been produced to evaluate the efficacy of using stainless steel materials as viable options to replace conventional steel prestressing strands and bars for use in concrete girders and slabs.

Chapter 1: Introduction

1.1 Problem Statement

Corrosion decay of structures has continued be a challenge in the scientific and engineering communities. In 1997 alone, the Intermodal Surface Transportation Efficiency Act (ISTEA) spent $2.5 billion for the Highway Bridge Replacement Program, where a majority of the funds went towards replacement or rehabilitation of bridge decks that were damaged by corrosion deterioration. Of the estimated 600,000 bridges in the United States, more than 25% are classified as structurally deficient and functionally obsolete. This would require an estimated $9.4 billion a year for 20 years to repair these aging bridges (ASCE, 2005).

Fig. 1: Corrosion of rebar in a bridge deck overhang
Source: http://www.empire-solutions.com/bridges.html

The Maryland State Highway Administration (SHA) is not immune to this national crisis. Maryland spends a great portion of its yearly bridge funding allocation on performing repairs and rehabilitations on its aging bridge inventory. In an effort to turn this trend around, SHA has tried to monitor problematic design practices and adjust present designs to avoid future maintenance issues. One area that has been particularly problematic for SHA is deterioration of prestressed steel strands in prestressed concrete beams and girders. Previous studies have shown that inadequate structural details, improper construction practices, and low-quality materials have accounted for the vast majority of poor performance leading to corrosion of prestressed structures. It has been noted that epoxy-coatings may perform less than intended, and can lose adhesion once chlorides reach certain levels of the steel reinforcement (Sagues et al., 1994; Smith and Virmani, 1996; Manning 1996). As such, there is a need to use alternative protective measures like dense concretes, corrosion inhibitors, nonmetallic and steel-alloy corrosion-resistant reinforcement (CTRE, 2006).

SHA has performed emergency span replacements on two different bridges because the stands had deteriorated to such an extent that serious safety concerns were exposed. To address future problems in this area, SHA has increased the concrete cover requirements beyond code requirements in an attempt to prevent the onset of deterioration. This will help, but comes at a price. The strands are less effective and therefore more strands are often required. Therefore, there exists a need to explore other materials that can be used in prestressed concrete girders and slabs to provide durable corrosion protection and prevention of premature spalling or corrosion-induced cracking.

1.2 Scope of Work and Objectives

This synthesis study was focused on gathering critical information to determine the feasibility and accessibility of stainless steel and other materials to be considered as alternative materials for use in prestressed strands in concrete girders and slabs. The main objectives of this project were to:

(1) Conduct an extensive literature survey of best demonstrated practices for use and availability of stainless steel strands,
(2) Contact manufacturers of stainless steel strands directly to verify research facts and get contacts of clients that have used the material. A survey to manufacturers is also planned to document information and experiences from different manufacturers,
(3) Identify other materials that may achieve similar results and be more advantageous such as carbon fiber strands, and
(4) Synthesize all information obtained and compile a document that evaluates the aforementioned questions, information gathered and lessons learned, including recommendations for future work, if applicable.

1.3 Organization of Report

This report is divided into five chapters. Chapter 1 presents the problem statement, scope of work and objectives of this study followed by an outline of the report. Chapter 2 provides background information in the form of a literature review on the various types of corrosion resistant rebar. Chapter 3 showcases the data from the survey in addition to the data collected from stainless steel manufacturers. Next, Chapter 4 presents information on life-cycle cost analysis. Lastly, Chapter 5 presents a summary of the work, recommendations, and a discussion of future work.

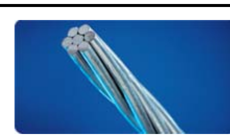
Chapter 2: Literature Review

2.1 Background on Corrosion Resistant Rebar (CRR)

Since steel corrodes in the presence of water and oxygen, various corrosion resistant rebar (CRR) are presented and evaluated for consideration as alternatives to conventional steel prestressing strands and bars. Details of the causes and effects of corrosion of prestressing steel can be found in a comprehensive study titled, *Report on Corrosion of Prestressing Steel (ACI 222.2R-14).* Table 1 provides a description of the bars as well as pros/cons reported by Bergmann and Schnell (2007):

1. epoxy-coated rebar (ECR),
2. galvanized steel,
3. Zinc-ECR (Zn-ECR),
4. Microcomposite Multistructural Formable (MMFx2) steel,
5. fiber reinforced polymer (FRP) bars,
6. stainless steel clad, and
7. solid stainless steel.

Table 1: Overview of various corrosion resistant rebar (CRR)

Rebar Material	Description	Pros/Cons	Image
ECR	epoxy-coated strand available in 2 configurations: coated and coated-and -filled	provides longer life than uncoated steel; poor bond with cement paste, fragility and adherence of coating	
Galvanized steel	protects steel from corrosive chemicals and provides sacrificial anodes	better bond to cement (compared to ECR), less fragile; limited life of coating; cannot be used with uncoated steel because coating will sacrifice itself to protect uncoated steel	
Zn - ECR	rebar is sprayed with molted zinc and epoxy	further tests are being done, very similar to ECR and galvanized; bond and fragility issues may be of concern	

Rebar Material	Description	Pros/Cons	Image
MMFX2 Steel	low carbon chromium proprietary alloy	good bond, no fragility issues, 0.2% deformation yield; poor ductility and higher initial costs than ECR or Galvanized	
FRP bars	composite materials made of a polymer matrix reinforced with fibers	estimated life expectancy of 65 to 100 years; low elastic modulus	
Stainless Steel Clad	stainless-clad under development but stainless-clad mild reinforcement has been used	need to cap cut ends to avoid corrosion of steel base; stainless-clad prestressed reinforcement remains in the research phase; limited availability in the U.S.	
Solid Stainless Steel	used successfully in corrosive environments	long life (~100 years), corrosion resistant, high strength with good ductility; no fragile coating and no need to cap ends; higher initial cost (2.5-4 x carbon steel)	

2.1.1 Epoxy-coated rebar (ECR) and prestressing bars

An epoxy-coating is used to protect conventional black steel from salts and other chemicals that may affect the rebar. However, due to its poor adherence, corrosive salts have been known to penetrate through epoxy-coated rebar (ECR). Because of its thin layer and weaker chemical composition, ECR is only projected to have 5 to 10 years of additional life over the standard of carbon steel given that the epoxy-coating can get either peeled of or nicked due to weathering and/or handling. Sizes for these bars can range from 0.007 to 0.012 inches (ASTM A775/A775M).

Epoxy-coated prestressing bars possess high-strength and have been used for post-tensioning applications. They are coated according to ASTM A775/A775M, which is the same standard for epoxy coating of mild steel reinforcement (ACI 222.2R-14). Epoxy-coated prestressing bars can get damaged during transport and handling just like epoxy-coated rebar although a two-part liquid epoxy can be used on site to repair damaged coating.

2.1.2 Galvanized prestressing steel and strands

Galvanized prestressing steel is similar in function to that of epoxy-coated prestressing steel where it protects the bar from corrosive chemicals but the disadvantages are their limited life of the coating especially on high-strength steel and the reactivity with cement paste in a highly alkaline environment. As such, corrosion rates of zinc can be very high (ACI 222.2R-14).

While the use of galvanized prestressing strand is prohibited by FHWA for use in bridges, they have been used in Europe and Japan (ACI 222.2R-14). It is known that the galvanizing process can affect the material properties of the strand given its cold-drawn process, thereby potentially reducing tensile strengths and degrading relaxation properties. Galvanized seven-wire strands are available in 3/8 to 0.6 in. diameter and in standard grades (ACI 222.2R-14).

2.1.3 Zn-ECR and MMFX2 steel

Zn-ECR differs from ECR in that the rebar is first coated with molten zinc, and then the epoxy (i.e. 2-mil layer of arc-sprayed zinc and then epoxy). Based on a few tests, the molten zinc is suggested to be the only other form of rebar material that could withstand the life expectancy of stainless steel. Microcomposite Multistructural Formable (MMFX2) steel has also been posed as a corrosion resistant bar with a low chromium alloy of 9% with high tensile properties. Even though the lifespan is predicted to be longer than ECR and galvanized steel, and expected to have good bond towards the cement paste, the main drawback of this material is its sole source and poor ductility. Also, there are no actual calculations for the yield strength, yet it has been reported to exhibit high yield deformations on the order of 12%.

2.1.4 Fiber Reinforced Polymer (FRP) bars

FRP bars are also projected to last for 75 years or more. Some disadvantages of FRP (glass, carbon and aramid are common types of FRP) are its low elastic modulus (about 2 to 3 times less than steel) and poor bonding with cement paste. However, the flexible nature of FRP is not a total disadvantage. Full-scale tests of bridge decks tested by Pirayeh Gar et al. (2013) have revealed that prestressed and non-prestressed bars within a bridge deck can be engineered to satisfy AASHTO LFRD (2012) strength and deflection criteria. Several studies have been performed on the use of FRP bars in bridge decks with promising results (Erki et al., 1993; Balendran, 2002; Kawaguchi, 1993; Dolan, 1990). Of course, higher initial costs can be expected but most experts estimate a life span of 65 to 90 years in service conditions before the loss of strength is unacceptable (CITRE 2006).

2.1.5 Stainless Steel Clad

Researchers have found that stainless steel cladding serves as an excellent corrosion protection for carbon steel bars except at the cut ends where a cap is needed to minimize corrosion of the carbon steel base (Clemena et al., 2004). The results reflect that the clad bars and the stainless steel bars tolerate the same chloride concentrations without corroding. The threshold level of these bars was about 15 times that of the conventional carbon steel bar. The researchers found that stainless steel clad bars are just as corrosion resistant as pure stainless steel bars, which is helpful because it provides a favorable alternative at a lower cost than solid stainless steel (CTRE 2006). However, the use of stainless steel clad is still undergoing more research to validate its performance (ACI 222.2R-14), and there is limited availability of these materials in the United States (CITRE 2006).

2.1.6 Solid Stainless Steel

According to tests conducted by the Federal Highway Administration (1998), stainless steel rebar is expected to last for about 100 years in the northern states of America. The typical types of solid stainless steel are type 304, 316LN and type 2205, which are very high in tensile strength with excellent fatigue characteristics. Grades 316LN and 2205, respectively, have good low-temperature toughness around -269 degree Celsius, where toughness is measured by impacting a small sample with a swinging hammer, and the distance by which the hammer swings after impact is the actual measure of toughness. The shorter the distance, the tougher the steel as the energy of the hammer is absorbed by the sample (Smith, 2007). Grades 316LN and 2205 have excellent corrosion resistance and can last over 100 years. On the other hand, Grade 304 is less corrosion resistant than the other two grades due to its Pitting Resistance Equivalent Numbers (PRENs).

The PRENs are equal to the percentage of the Chromium (Cr) plus 3.3 % of Molybdenum (Mo) plus 16% Nitrogen (N). Table 2 shows the percentage for each alloy and its known PRENs values. Alloys with higher PRENs have greater resistance to chloride pitting when the risk of the chloride is high on the concrete; in fact, it is better to select a bar material with high PREN for that reason. Note that Grade 316LN has a PREN value of 27 and Grade 2205 has a PREN value of about 34. "Reducing the future maintenance and/or repair costs of reinforced concrete structures thereby increases the life-cycle cost of the bridge and overall project costs, which is one advantage for using stainless steel rebar" (Smith, 2007). In addition, stainless steel rebar is ductile, has the capability of 3 times its diameter for bends, and can be welded together for the commonly used grades. Moreover, solid stainless steel does not need to be coated or covered (Smith, 2007). One disadvantage of the stainless steel rebar compared to other materials such as carbon steel is its cost. The cost of the stainless steel can be around \$2.30/lb when installed compared to about \$0.50/lb of carbon steel when installed (Schully, 2007). Talley Metals, a Carpenter Technology Corporation Company, has a lower cost stainless steel alloy called EnduraMet®32, which has been used as reinforcement in steel. EuduraMet®32 stainless has far exceeded proposed ASTM corrosion macrocell testing in a simulated pore solution given its 0.015 µm/year average compared to the ASTM requirement of 0.25 µm/year average. In short, prices can change (i.e. lessen) when larger quantities are ordered. For corrosion resistant rebar presented in general, there will be a higher initial cost, but will serve as an investment over the life-cycle cost of the structure.

Table 2: Chemical Composition of Stainless Steel Rebar

Alloy	UNS No.	Cr	Ni	C	Mo	N	PRENs
316LN	S31653	17	12	0.03	2.5	0.13	27
2205	S31803	22	5	0.03	3.0	0.14	34

2.2 Case Studies – Field Application of Stainless Steel

Common practice in construction has been to use conventional carbon steel reinforcement bars and concrete. In more recent years, DOTs have conducted pilot projects to monitor the benefits of using alternative materials such as stainless steel strands and rebar for reinforced concrete. Since a lot of these projects are fairly new, there is not a lot of evidence to support the claim that stainless steel rebar is better than conventional carbon steel. However, from a chemical aspect, there is a lot of evidence that explains how stainless steel rebar is more durable and less susceptible to harsh elements such as deicing salts and other chemically aggressive environments. Therefore, it will not corrode as quickly as carbon steel and this minimizes concrete deterioration.

In order to explore the possibilities of future reinforcing bar applications, experimentation must be conducted to rank the chloride thresholds of different types of steel rebar from most to least corrosion resistant. Researchers predicted that the material with the highest Pitting Resistance Equivalence Number (PREN) would be the material with the highest corrosion resistance (Smith, 2011). Potentiostatic laboratory test methods have been used to try to understand corrosion initiation and propagation stages of the steel rebar, but their hypothesis was disproved (Smith, 2011). Differences in the chloride thresholds did not only depend on material composition. Surface condition and the presence of any microstructural or physical defect can also alter the chloride threshold, which is affected by a variety of physical and environmental factors.

2.2.1 Woodrow Wilson Bridge (MD SHA/Virginia DOT)

The original Woodrow Wilson Bridge (WWB) was constructed in 1961 to carry Interstate 95/495 over the Potomac River and to connect Alexandria, Virginia to Washington, DC. The bridge had 6 lanes with very narrow shoulders and was designed to accommodate 75,000 vehicles daily. By the 1980's, the bridge had nearly twice the accident rate as similar highways in Maryland and Virginia. It was overwhelmed with at least 7 hours of traffic congestion and 200,000 vehicles daily (Ruddell, 2007). The narrow shoulders provided no space for motorists involved in accidents to pull over so there were frequent mile long backups daily. Extreme wear and tear on the almost 40-year-old bridge required the structure to be replaced in the near future. In 1988, the federal government, Maryland, Virginia and the District of Columbia initiated the planning to have the WWB replaced. The new WWB was opened to traffic in July 2006. The new bridge replaced nearly 12 percent of the Capital Beltway (Interstate 495/95) and created four new interchanges, resolving one of the worst bottlenecks on the East Coast. Contractors used about 1100 tons of stainless steel on the bascule spans of the bridge to prevent corrosion of this portion that could be caused by exposure to deicing chemicals and moisture from the river.

2.2.2 US 2 Bridge over Winooski River (Vermont Agency of Transportation)

In March 2009, Vermont Agency of Transportation made stainless steel reinforcing standard for bridge superstructures on high traffic pavements. The Agency classifies Vermont's roads into three levels. Level 1 and 2 includes non-paved roads and roads that are not on the National Highway System and epoxy-coated reinforcement is permitted. The third level is for heavily traveled pavements and stainless steel reinforcement is required. The Agency conducted a demonstration project with the Highways for Life (HFL) program to replace the US 2 Bridge over Winooski River in East Montpelier. This project involved rapidly removing a very narrow, failing, three-span two-lane concrete bridge on a key access route and replacing it with a single span integral abutment bridge. HFL contributed a $568,255 grant to the bridge replacement because of its innovation and reduced construction time. Key innovations include the use of weathering steel girders, a deck of bare High Performance Concrete (HPC) along with stainless steel reinforcement and curbless flush-mounted pedestrian rails. Also, the project was completed in one season instead of two and the traffic was maintained during construction by use of a two-way bypass bridge. This bypass bridge provided increased motorist and worker safety. The simple span design, use of stainless steel reinforcement and HPC provided a maintenance-free structure. This $2.84 million project was slated to save $975,000 in maintenance and replacement costs compared to the $94,500 initial increase in cost.

2.2.3 Missouri DOT

The Missouri DOT constructed its first cast-in-place bridge deck using stainless steel reinforcing bars in 2006 (Wenzlick, 2007). A control bridge was constructed using epoxy-coated rebar. The bridges had identical roadway lengths and girder spacing but different span lengths and skews. They were constructed on the same route, only about 600 feet apart from one another. These factors allowed for good evaluation of the durability and performance of the subject bridge deck in comparison to the conventional deck. Researchers hypothesized that the stainless steel reinforced bridge deck would be longer lasting. Only some preliminary, comparative results like the prices of rebar and the properties of the deck concrete were provided. It was reported that the black steel may have corroded because there was already some level of chloride in the concrete mix. The hypothesis was supported in that the stainless steel rebar was more beneficial to use because it did not corrode with time. However, these conclusions were drawn solely based on a visual inspection because the study did not yield as much data, as hoped, from the instrumentation that was installed.

2.2.4 Virginia Transportation Research Council (VTRC)

The Virginia Transportation Research Council (VTRC) conducted a project to search for metallic reinforcing bars that were durable and corrosion resistant, but also economical. The corrosion of carbon and epoxy-coated steel reinforcing bars has been the major cause of premature deterioration of many of our nation's concrete bridges (Clemena, 2003). The four alternative corrosion resistant rebar (CRR) types used in this research were (1) stainless steel-clad carbon steel bars, (2) MMFX-2 "microcomposite" steel bars, (3) the new 2101 LDX duplex stainless steel bars, and (4) carbon steel bars coated with a 2-mil layer of arc-sprayed zinc and then epoxy. The researchers embedded these bars into concrete blocks and subjected them to several weeks of ponding with a saturated salt solution and drying. They also did the same testing with two solid stainless steel bars (304 and 316LN) and a carbon steel bar (ASTM A615) for comparison. Researchers found that the presence of a macrocell current between the bars is a definitive indicator of the beginning of corrosion of a steel bar (Clemena, 2003). Researchers developed plots to display the weekly macrocell currents of concrete blocks with the different types of metallic material to reflect that the black steel is the least corrosion resistant, of course. The pure stainless steel, clad and Zn/EC bars were the most and relatively equally corrosion resistant yet solid stainless steel can deliver optimum structural properties based on studies to date (CTRE 2006).

2.2.5 New York State DOT

New York State DOT has designed a few bridges with solid stainless steel reinforcing in the deck for various reasons, where they offset some of the additional cost of solid stainless steel (combined with lightweight concrete in one case) by design efficiencies elsewhere in the project (CITRE 2006). The first example is the Alexander Hamilton Bridge, a steel riveted spandrel arch bridge over I-95 across the Harlem River. The project called for deck replacement, widening, steel rehabilitation and seismic upgrades given increased dead load thereby requiring significant reinforcement of the existing riveted steel spandrel arch ribs and spandrel columns. However, solid stainless steel reinforcing was deployed, making the addition of reinforcement unnecessary while reducing overall costs and construction time.

Another stainless steel project was the Undercliff Avenue Bridge, which supports a local street over the eastern approach to the Alexander Hamilton Bridge. The replacement structure needed to span more than 100 feet with welded plate girders that were 32 inches deep with spacing of less than 6 feet. However, the use of stainless steel reinforcement allowed for a 1 inch savings in the deck thickness to be applied to the girder depth, enabling one girder to be totally eliminated and reducing the overall cost of the project.

Similar to the Undercliff Avenue Bridge project, the Major Deegan Expressway Viaduct was in need of deck replacement, widening, steel rehabilitation and seismic upgrades as well. However, stainless steel reinforcing and lightweight concrete in the deck made the need for the estimated 16 new pile-supported foundations to be unnecessary, therefore, reducing the cost of the seismic upgrades.

2.2.6 Summary

In summary, each CRR has its advantages and disadvantages while comparing the benefit to the cost for a specific project. From the literature reviewed for this synthesis study, the pure stainless steel, clad and Zn/EC bars were the most and relatively equally corrosion resistant yet solid stainless steel can deliver optimum structural properties based on studies to date (CTRE 2006). It is important to note that the corrosion rates in bridge decks have been associated with the amount of cracking (Smith and Virmani, 1996; Fanous et al., 2000). As such, ways to minimize cracking can also be addressed in addition to finding other alternatives than employing CRR, which is addressed in the next chapter that showcases the survey results.

Chapter 3: Survey Assessment and Manufacturer Data

3.1 Survey Overview

A survey was designed to capture expert responses with a purpose to assess the state of practice for methods of corrosion protection of prestressed beams and girders with special emphasis on encounters and best practices of stainless steel rebar and/or strands. This 10-question survey was administered in October 2013 and 33 responses were received. The objective of conducting the survey was to document information and experiences pertaining to the feasibility and accessibility of stainless steel strands. The IRB-approved survey was administered (http://www.surveymonkey.com/s/PJKHRDD) and the results can be viewed online at https://www.surveymonkey.com/results/SM-33L523G/. A copy of the survey can be found in Appendix A of this report.

3.2 Target Audience

The survey was distributed in conjunction with representatives from the Concrete Division and Structural Materials Division of the SHA Office of Materials Technology. The target audience included employees of various DOTs, precast plants, academic institutions and engineering firms. Researchers were particularly interested in the responses rendered from the precasters and mill representatives given their first-hand experience with the cost and effectiveness of the corrosion resistant materials in question. The following is a list of the agencies and precast mills that participated in the survey:

- Connecticut Department of Transportation
- Louisiana Department of Transportation and Development (LA DOTD)
- Slaw Precast
- Arizona Dept. of Transportation (ADOT)
- Caltrans METS
- NDDOT
- Iowa DOT
- ILL Depart of Transportation
- Kansas DOT
- Utah DOT
- State of Maine Department of Transportation
- WVDOH
- Central Atlantic Bridge Associates
- Northeast Prestressed Products
- Washington State DOT
- KY Department of Highways
- Minnesota DOT - Bridge Office
- North Dakota Department of Transportation
- State of Alaska Dept. of Transportation and Public Facilities
- Saskatchewan Highways and Infrastructure
- Nebraska Department of Roads
- PennDOT

From the survey, respondents from 17 states participated and provided feedback (Fig. 2). It is important to note that the responses were throughout the United States with feedback from states that do experience snow and other freeze-thaw conditions by which salts and other deicing chemicals salts are used on roadways and bridge decks that can accelerate the corrosion of rebar, and the need to find alternative solutions with corrosion-resistant rebar.

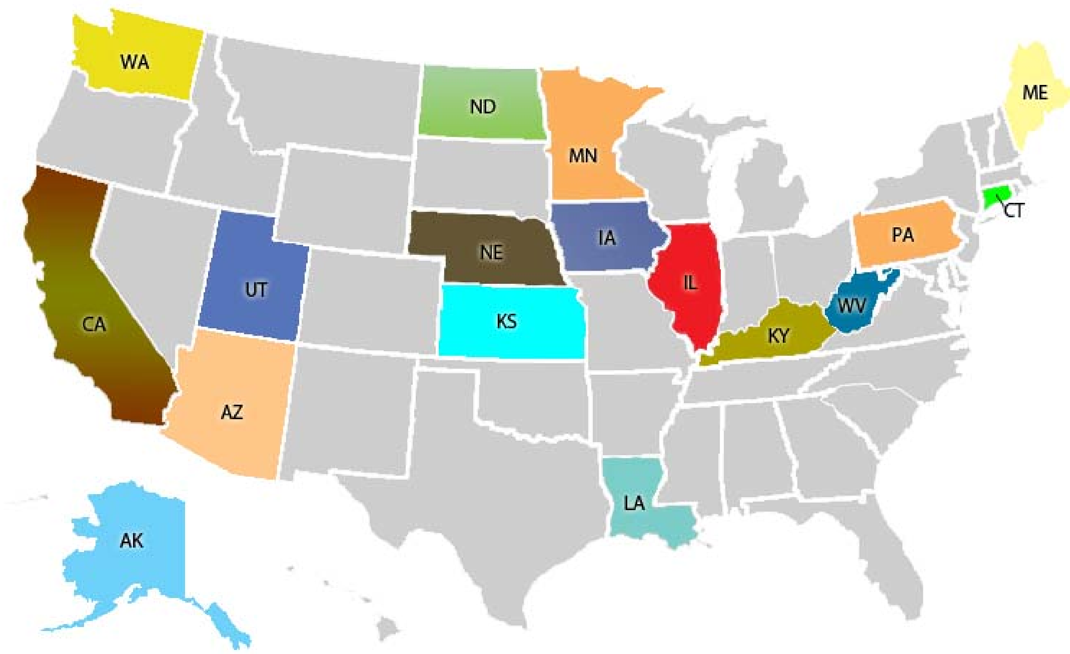


Fig. 2: Representation of survey respondents by state

3.3 Survey Analysis and Results

Very useful data was extracted from the survey responses. The questions started general inquiries about corrosion protection methods and went on to ask specifically about the respondents' experience with stainless steel rebar. Overall, it seemed that the majority of respondents were either not familiar with and/or did not have much experience with the use of stainless steel rebar, so information was also extracted on alternative strategies besides deployment of CRR to reduce cracking and therefore potential corrosion rates.

The first and last questions asked about the respondents' occupation and contact information so the technical results will come from questions 2-8. Graphical representations of the survey responses can be found in Figures 3-13. The highest recommended strategies to minimize cracking of precast elements from Question #2 are minimizing curing times and using alternative curing methods (plots shown in Appendix B). The most used or recommended strategies to prevent corrosion of reinforcement in bridge elements was reported to be through using epoxy-coated rebar, lowering the permeability of concrete and increasing clear cover depth (Figure 4). Some other examples include using High Performance Concrete (HPC or higher strength concrete as indicated in the survey) to reduce cracking of bridge decks by reducing heat of hydration and slowing strength gain. Of course, this results in slower curing times as well as higher initial costs, in general.

From Question #3, ranking of the effectiveness and financial benefit to prevent corrosion show that selecting a lower permeability concrete seemed to be the most effectively ranked strategy while using epoxy-coated rebar revealed the least financial benefit as considered by the respondents (Figures 11 and 12). Figure 13 reveals that increasing the clear cover distance provides a seemingly balanced effort when considering the financial benefit and effectiveness of the strategy. (Additional graphs of the data collected from Question #3 are shown in Appendix B). However, fifty-four percent (54%) of the respondents would not pay to use stainless steel on a project. It was expressed from the survey that stainless steel should only be used for projects that require a larger quantity of reinforcement because of its high price (Question #8).

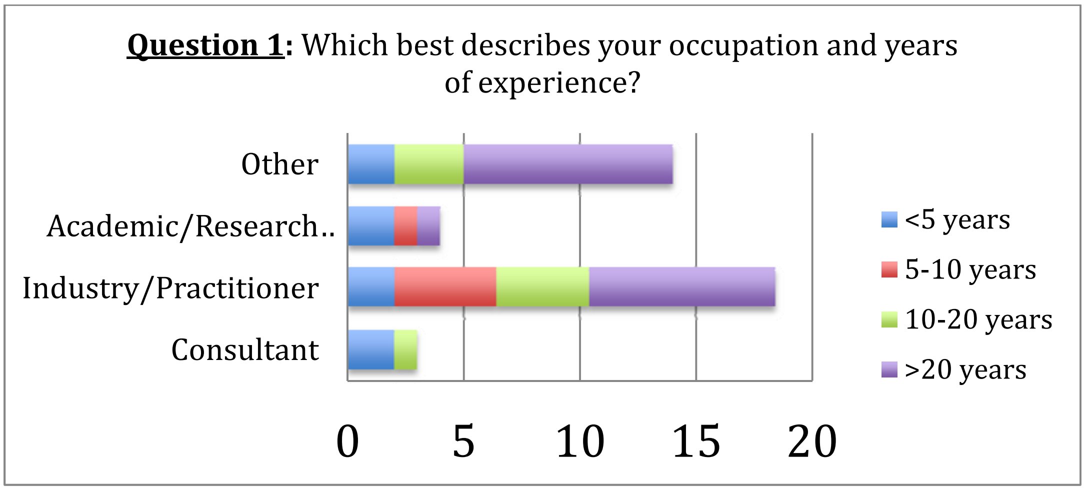


Fig. 3: Survey Question #1

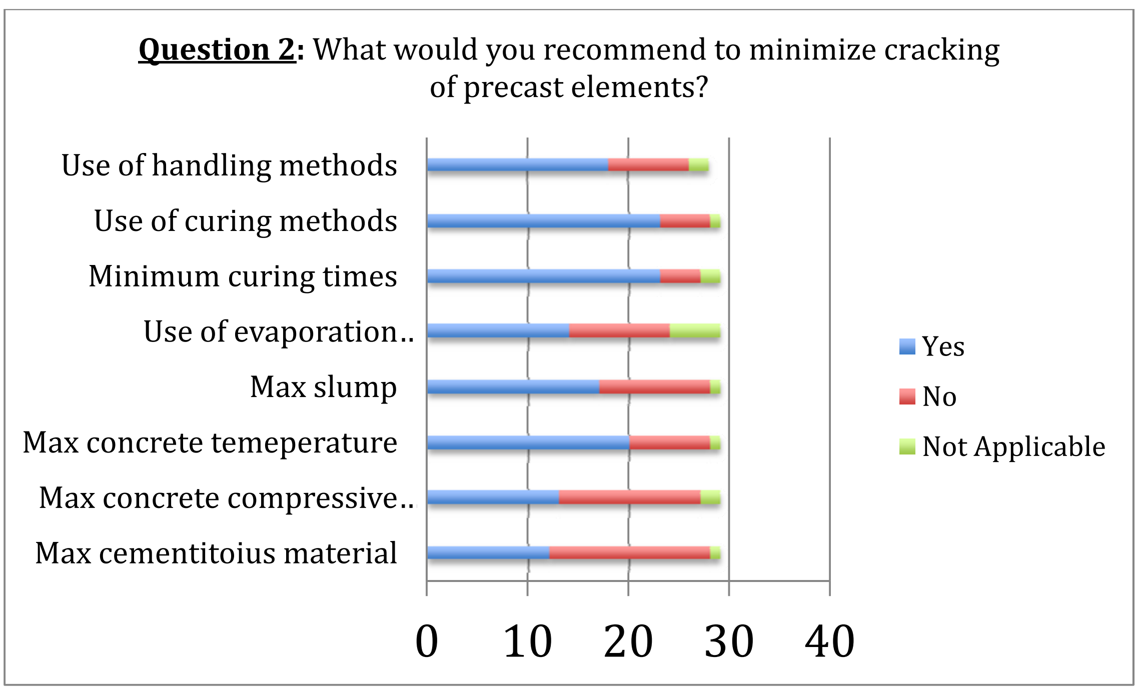


Fig. 4: Survey Question #2

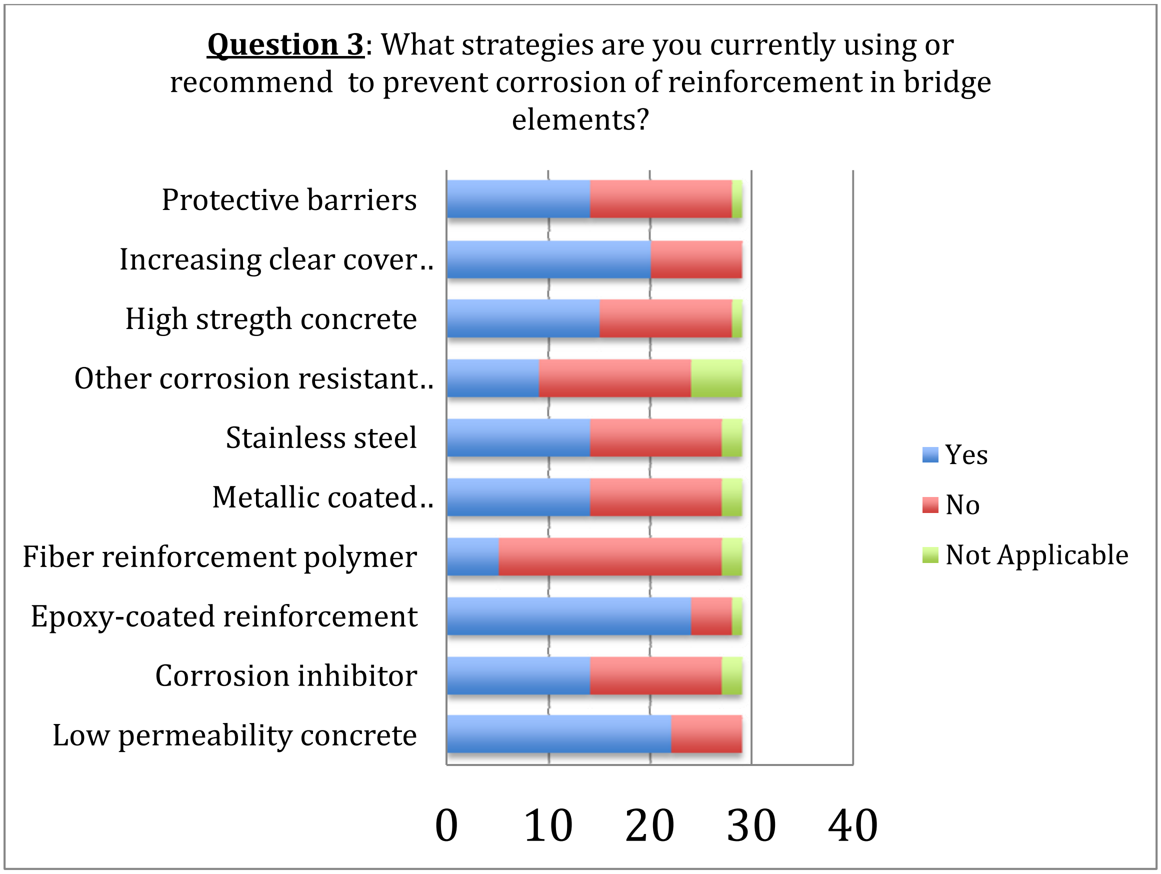


Fig. 5: Survey Question #3

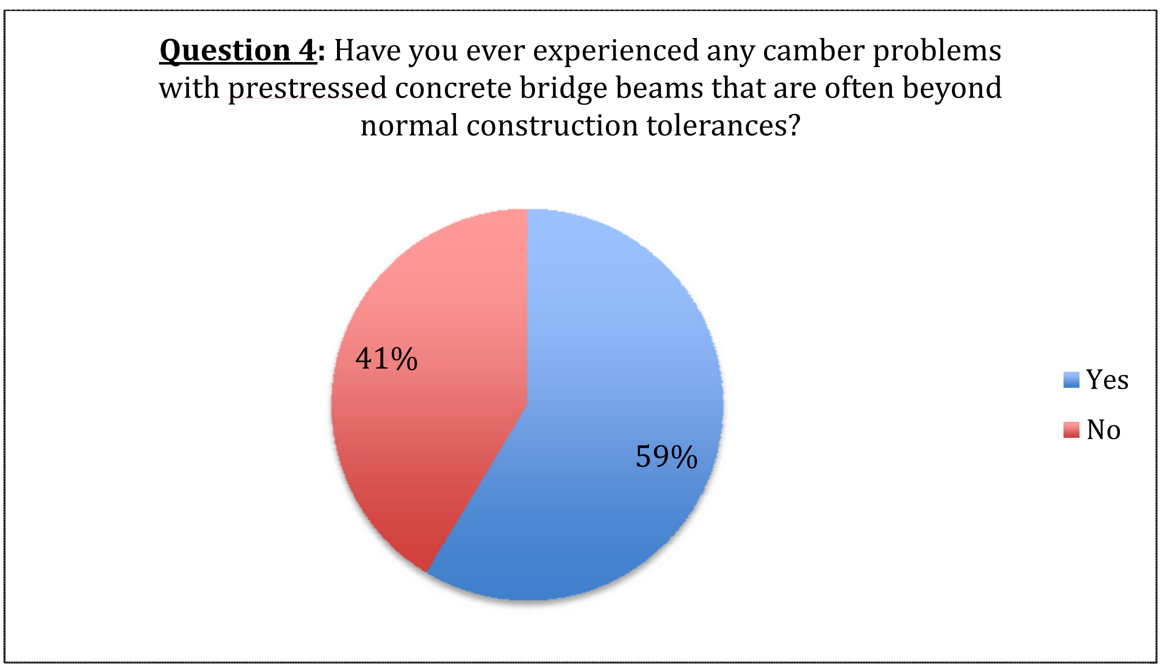


Fig. 6: Survey Question #4

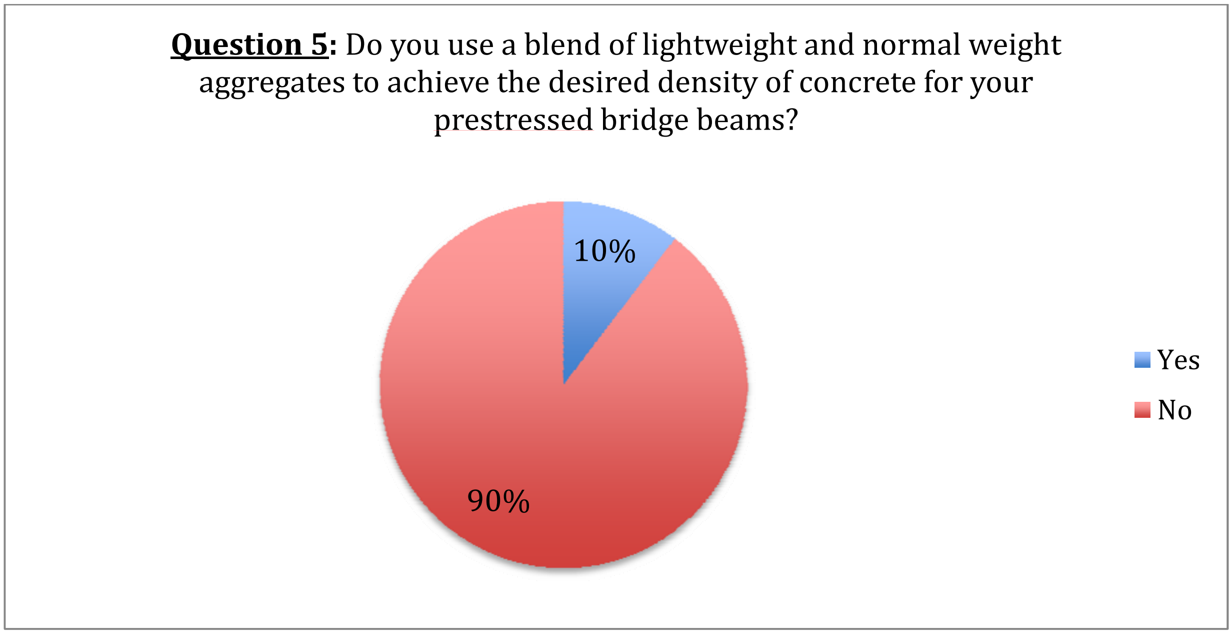


Fig. 7: Survey Question #5

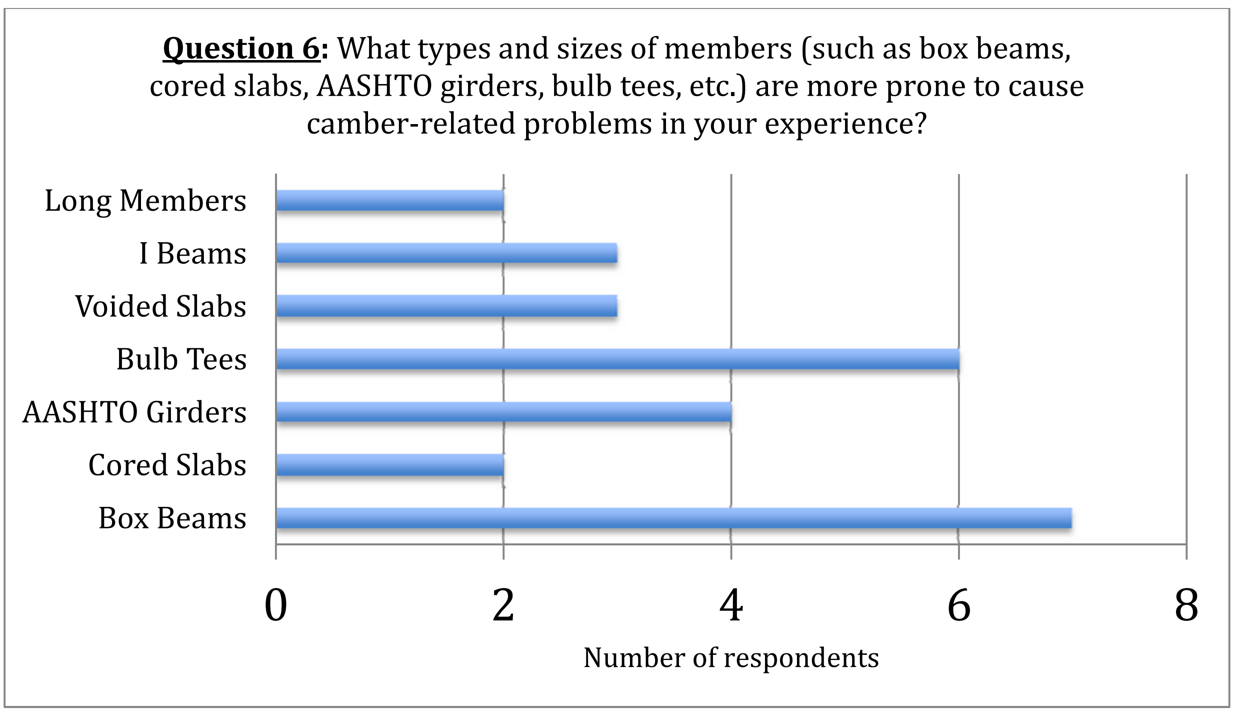


Fig. 8: Survey Question #6

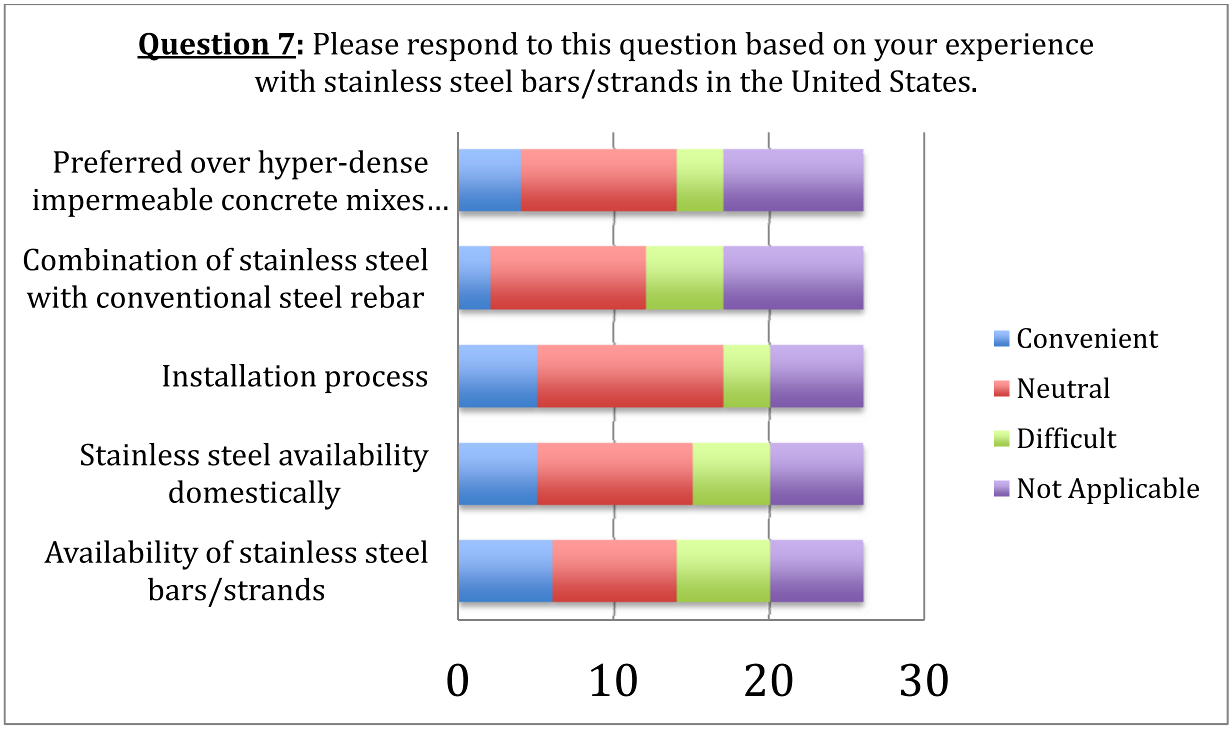


Fig. 9: Survey Question #7

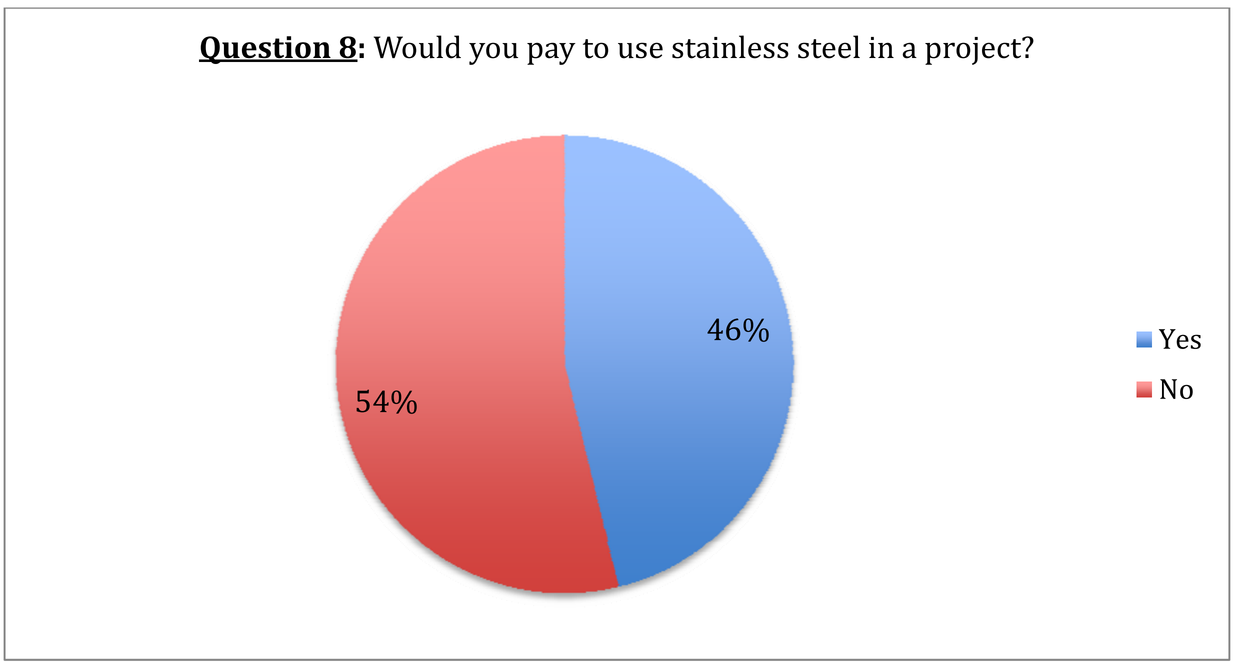


Fig. 10: Survey Question #8

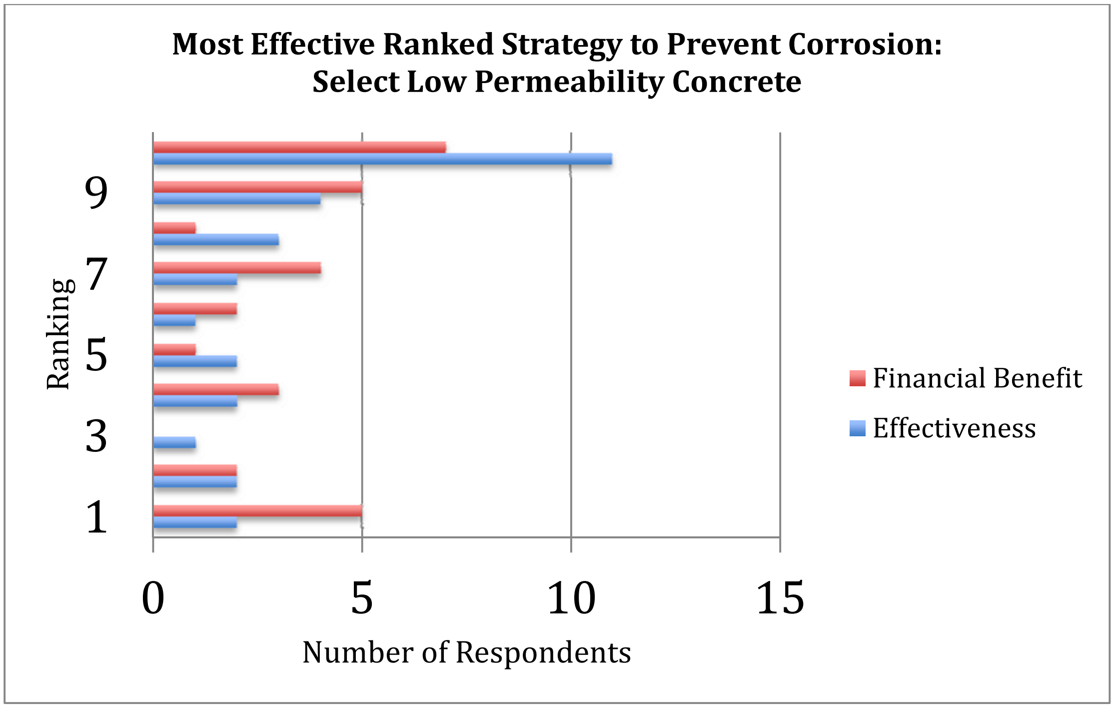


Fig. 11: Most Effective Ranked Strategy to Prevent Corrosion from Survey Question #3

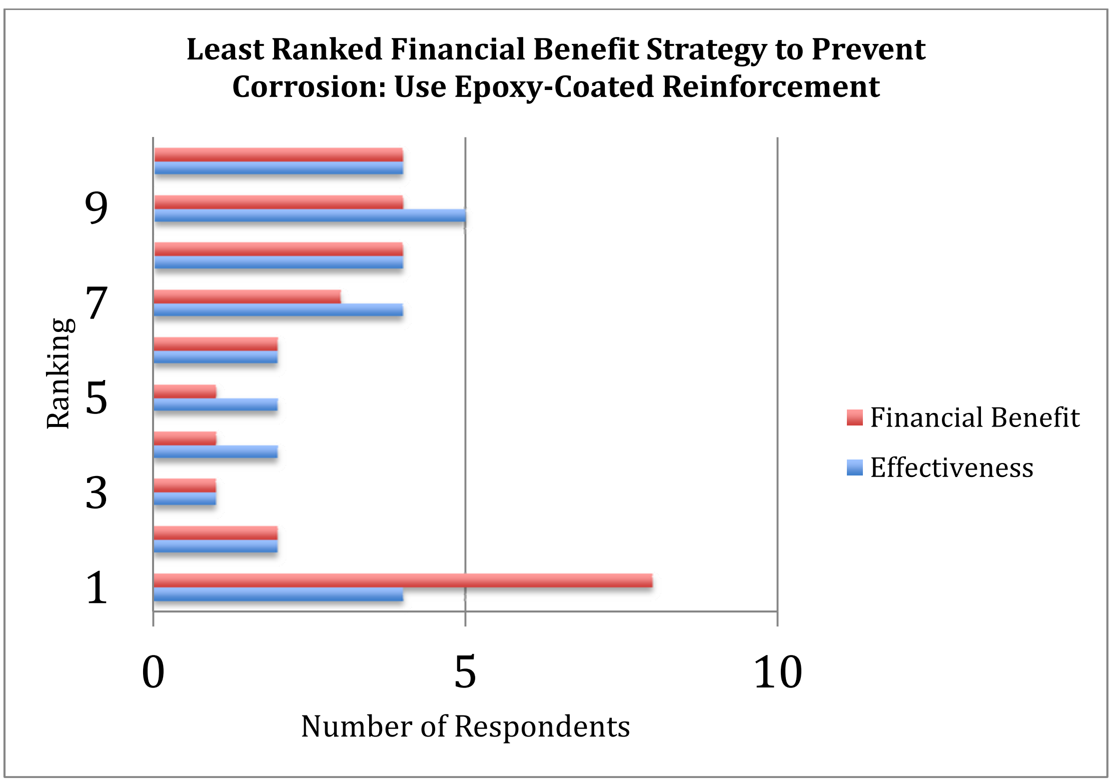


Fig. 12: Least Ranked Financial Benefit Strategy from Survey Question #3

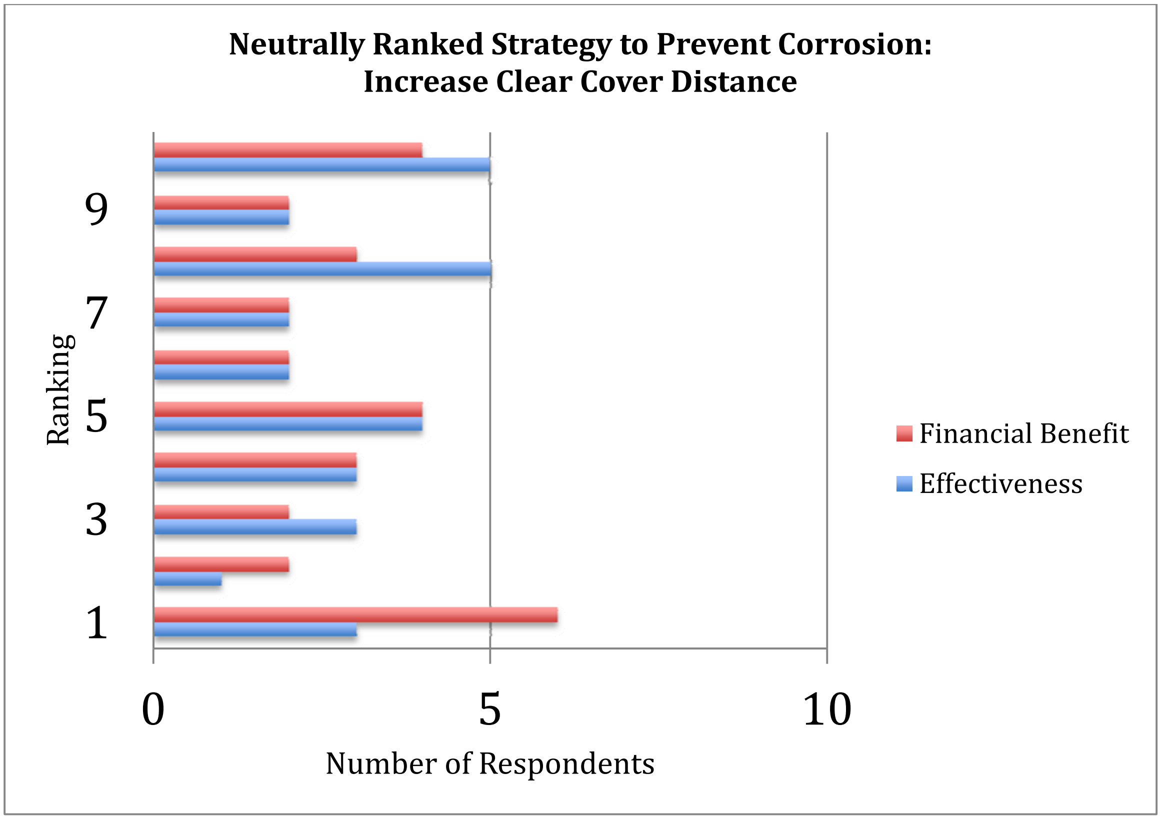


Fig. 13: Neutrally Ranked Strategy from Survey Question #3

3.4 Data Collected from Stainless Steel Manufacturers

From this study, several questions needed to be addressed in order to meet the ***main objective*** of determining the feasibility and accessibility of stainless steel prestressing strands and bars as materials to be considered for use in prestressed concrete girders and slabs. Table 3 shows a compilation of the responses to these inquiries.

Table 3: SHA Questions with Responses Provided by Study

MD SHA Inquiry	Response
What is the availability of stainless steel rebar/strands?	Three companies were found to melt and manufacture in the USA to strict quality standards: 1) North American Stainless in Kentucky (http://www.northamericanstainless.com/), 2) Talley Metals in South Carolina (http://www.talley-metals.com), and 3) Salit Specialty Rebar located in Niagara Falls, New York (http://stainlessrebar.com/). Sumiden Wire Products in Dixon, Tennessee manufactured both 2205 and 2304 strands for a research project funded by the Georgia DOT Research Project Number 10-26 by Lawrence F. Kahn (http://www.concretebridgeviews.com/i74/Article3.php). The survey revealed that there seems to be uncertainty on the availability of these materials in general and domestically (Question #7).
Are there domestic suppliers? Who are they?	Yes. More details on their product specifications can be found in Appendix C of this report in addition to their individual websites. North American Stainless, 6870 Highway 42 East, Ghent, KY 41015, Phone: (502) 347-6000, FAX: (502) 347-6001, Email: nasinquiries@northamericanstainless.com, Contact: Chris Lyons, Website: http://www.northamericanstainless.com/. Salit Specialty Rebar, 3235 Lockport Road, Niagara Falls, NY 14305, Phone: (716) 299-1990, FAX: (716) 299-1993, Email: kcornell@stainlessrebar.com, Contact: Kevin Cornell, Website: http://stainlessrebar.com/. Talley Metals, PO Box 2498, Hartsville, SC 29551, Phone: (843) 332-5849 x2121, FAX: (843) 335-5160, Email: sbrunson@cartech.com, Contact: Sharon Brunson, Website: http://cartech.com
What is the approximate cost per length?	North American Stainless reported approximately $1.90/ft.
What are the most common/popular types of stainless steel used?	Duplex 2304 was reported to be the most popular for bridge decks as reported by North American Stainless. Talley Metals Technology, Inc., a Carpenter company produces EnduraMet®32, 2205, 316LN, 33, and 2304 in sizes #3 through #38 in lengths up to 40 feet.

MD SHA Inquiry	Response
What are some sample projects for which these suppliers supported?	Salit Special Rebar has a listing of some of their stainless steel rebar projects throughout North America, Hawaii and the Caribbean, which can be found at: http://stainlessrebar.com/projects/.
Can they be installed the same way? Same equipment?	Stainless steel rebar shall be stored and handled using tools that are not used on carbon steel. Any mechanical connectors should also be stainless. Moreover, the stainless steel reinforcement shall not have direct contact with uncoated steel nor with galvanized reinforcement (exception: stainless steel wires and ties - https://www.dot.ny.gov/portal/pls/portal/mexis_app.pa_ei_eb_admin_app.show_pdf?id=10256). Field bending shall be done by cold methods only.
Are the strength and ductility the same?	Per ASTM A955M, North American Stainless provides three yield strength grades: 300, 420 and 520 MPa. While the typical strength grade for black carbon steel is 420 MPa, previous testing of the Carpenter Alloy 2205 stainless rebar has met the 520 MPa yield strength minimum with superior ductility. As such, these results are about 25% higher than the typical strength required. Two samples of No. 5 solid stainless steel rebar were tested and produced a yield strength of 580 MPa compared to the 520 MPa minimum requirement. The ultimate tensile strength was 790 MPa versus the minimum requirement of 725 MPa. More details can be found in the specifications info sheets in Appendix C.
Would it reduce current clear cover requirements that exceed AASHTO?	When stainless steel reinforcing is used, the cover can be reduced, saving costs of concrete and reducing the total weight of the structure.
Is the use of stainless strands more economical than the use of hyper-dense impermeable concrete mixes such as silica fume blends?	Studies by transportation agencies have shown that the use of solid stainless steel reinforcing bar can more than double the life of a bridge deck. It can also increase the cost of the bridge deck by as much as 12% compared to carbon steel reinforcing, but the economic value can outweigh initial costs. In most cases, the additional cost of solid stainless steel reinforcing bar represents approximately 1.5-3% of the total cost of the structure (Tally Metals).

MD SHA Inquiry	Response
Could the material be used in combination with regular prestressing strands?	Oregon DOT used 2205 stainless steel rebar along with a much larger volume of 614,000 kg of grade 60 uncoated carbon steel in a new bridge's substructure elements where corrosion was not a major concern. When used together, the stainless steel rebar was covered with a polyethylene (PE) sleeve where the dissimilar metals intersected to minimize the possibility of galvanic corrosion. An example with stainless steel rebar and prestressing strands was not found by the time of reporting. Conventional steel prestressing strands have been used in conjunction with stainless steel rebar in bridge piles tested by Kahn (2014) and referenced at: http://www.concretebridgeviews.com/i74/Article3.php.

Chapter 4: Life-Cycle Cost Analysis

4.1 Background and Life-Cycle Cost Analysis Case Studies

Life-Cycle Cost (LCC) is the sum of all recurring and one-time costs over the full life span or specified life of a good, service, structure or system. It includes purchase price, installation cost, operating costs, maintenance and upgrade costs, and remaining (residual or salvage) value at the end of ownership or its useful life. The service life of concrete bridges depends on corrosion of the reinforcing steel that is induced by exposure to chloride ions from substances like deicing salts and seawater. A study sponsored by FHWA estimated the annual direct cost of corrosion to be $8.3 billion for highway bridges (Koch et al., 2002).

In efforts to find an alternative for carbon steel rebar, researchers have revealed a way to achieve the durability of stainless steel rebar while maintaining the cost of conventional carbon steel rebar. "Austenitic stainless steel cladding over carbon steel is an attractive alternative to solid stainless steel from both a cost and corrosion mitigation standpoint" (Schully et al., 2007). However, further studies are required to analyze the resulting corrosion behavior when a break in the clad layer occurs, exposing the carbon steel core. There are two very different situations that can cause the exposition of the carbon steel core. Either there is significant localized corrosion through the clad layer or there is some mechanically induced damage.

The Virginia Transportation Research Council (VTRC) conducted a study with the purpose of developing service life estimates of concrete bridge decks and costs for manipulating concrete bridge decks for 100 years (Williamson et. al., 2007). The researchers used a probability based chloride corrosion service life model to estimate the service life of bridge decks built under different concrete and cover depth specifications between 1969-1971 and 1987-1991. They also evaluated the possibilities of using alternative reinforcing materials such as solid stainless steel and stainless steel clad bar as a secondary corrosion protection method. Life cycle costs were estimated for maintaining the bridge decks for 100 years using both present worth and inflated costs. They found that the service life of Virginia's concrete bridges depends on the corrosion of the reinforcing steel that is induced by exposure to chloride ions from substances like deicing salts and seawater. Due to a change in the VDOT specification that dictates a water-to-cement (w/c) ratio of 0.45 instead of 0.47 and a cover depth of 2.75" instead of 2", all of the bridges tested in this project were not constructed in the same way. The most significant conclusions were that, "the time required for corrosion to induce cracking in the cover concrete can be estimated using existing corrosion-cracking models. An estimated time to corrosion cracking of 6 years for bare steel reinforcement was determined for this study." "The addition of fly ash or slag to the sampled bridge deck concrete mixture appears to dramatically reduce the diffusion rate of chlorides into concrete and have equivalent long term corrosion protection effect" and "the service lives of bridge decks constructed under current specifications (0.45 w/c and 2.75" cover depth) are expected to exceed a design life of 100 years regardless of reinforcement type" (Williamson et. al. 2007). The researchers recommended that newly constructed bridge decks be built under the current specifications with w/c=0.45 and 2.75" cover depth with conventional steel reinforcement. The reason why researchers did not recommend the use of alternative reinforcements over the use of bare steel reinforcements is because of the determination that the service lives of bridge decks constructed under current cover depth and low permeable concrete specifications are expected to exceed 100 years regardless of reinforcement type. So reinforcement types were selected on a first-cost basis.

4.2 Life-Cycle Cost Analysis (LCCA) Estimates from Case Studies

This section focuses on finding an approach to estimate the life-cycle cost of the corrosion resistant rebar (CRR) presented by first analyzing how existing LCCA have been conducted by previous researchers. The Michigan DOT has also conducted estimates for life-cycle cost analysis (LCCA) of stainless and stainless-clad reinforcement for highway bridge use (Kahl 2011). Section 4.2.2 will outline a recommended approach based on all of the information presented. This will aid SHA in identifying the efficacy of selecting one of these materials to replace conventional black steel for one of their projects.

4.2.1 Case Studies

Researchers have found three plausible approaches to determine the LCC of a concrete bridge. Continental Automated Building Association (CABA), National Cooperative Highway Research Program (NCHRP) and Nickel Development Institute (NiDI) developed the three approaches. Equations for these three approaches can be found in Table 4. The factors included in these approaches are First Cost (FC), which includes the costs of design, materials, fabrication and installation, Maintenance Cost (MC), Inspection Cost (IC), Future Rehabilitation Cost (FRC), User Costs (UC), Lost Production Cost (LPC), Material Related Cost (MRC), time period of analysis (t), present worth factor (pwf) and Salvages costs/values (S). In order to determine LCC using the equations developed by CABA and NCHRP, one would have to calculate UC (Table 5). This factor includes the vehicle operating cost, delay of use cost and accident cost. In order to compute these costs, one needs to know the length of the affected roadway, normal traffic speed of the roadway, traffic speed during maintenance activity, and average daily traffic. These figures are going to vary with every LCC calculated. For general research purposes, researchers found the third approach from NiDI to be the most feasible.

Table 4. Three Life-Cycle Cost Analysis (LCCA) Approaches

Agency	Equation
CABA*	$PW = FC + \sum_{t=1}^{t=n} pwf[MC + IC + FRC + UC] + pwf[S]$
NCHRP	$LCC = FC + MC + FRC + UC + S$
NiDI	$LCC = FC + MC + FRC + LPC + MRC$

*CABA calculates LCC in terms of Present Worth (PW)

An economic analysis, using the LCC approach developed by NiDI, was conducted using figures from the replacement of the Schaffhausen Bridge in Switzerland. This bridge was replaced in 1995 and a cost comparison for using carbon steel, epoxy coated steel and stainless steel was conducted at the time. Researchers used inflation rates to project what these costs would be in the present day. Although the material cost of the stainless steel quoted for the Switzerland bridge example was more than ten times that of the carbon steel, the elimination of replacement cost saved more than $2 million from the LCC for the stainless steel bridge. The full economic analysis/LCCA calculation can be found in Table 6.

Table 5. LCCA Equation Factors

LCCA Equation Factors	*FC	MC	IC	FRC	UC	LPC	MRC	t	pwf	S
CABA	✓	✓	✓	✓	✓	–	–	✓	✓	✓
NCHRP	✓	✓		✓	✓	–	–	–	–	–
NiDI	✓	✓	✓	✓	–	✓	✓	–	–	–

*Please note the following designations:

FC= First cost (includes Design, Material, Fabrication & Installation cost)
MC= Maintenance cost
IC= Inspection cost
FRC= Future Rehabilitation/Replacement cost
UC= User cost
LPC= Lost Production cost
MRC= Material Related cost
t= time period of analysis
pwf= Present worth factor
S= Salvage costs/value

Table 6. Economic Analysis of the Schaffhausen Bridge in Switzerland

	Carbon Steel	**Epoxy Coated Steel**	**Stainless Steel**
Material Cost	$8,551	$32,778	$92,477
Fabrication Cost	0	0	0
Installation Cost	$16,285,930	$16,285,930	$16,285,930
First Cost	$16,294,481	$16,318,708	$16,378,407
Maintenance Cost	0	0	0
Replacement Cost	$267,311	$80,193	0
Lost Production Cost	$2,314,388	$2,314,388	0
Material Related Cost	0	0	0
Operating Cost	$2,581,699	$2,394,581	0
Total LCC	$18,876,180	$18,713,289	$16,378,407

4.2.2 Proposed Life-Cycle Cost Analysis (LCCA) Sample Calculation for SHA

Economic comparisons were used in this case study to compare and contrasts the cost relations for each rebar. FHWA uses a life-cycle cost analysis based off the estimated rate of discount of the interest rate minus inflation. According to Schnell et al. (2007), the cost of carbon and stainless steel are undergoing financial growth delay. To provide some analysis for their argument, Bergmann et al. (2007) compares the cost of epoxy-coated reinforcement with stainless steel over the entire bridge deck based on pricing of both materials for use in New York City. If the price of stainless steel in New York was almost three times as large as ECR in bridge decks and the average ECR used in bridge decks is 12%, then stainless steel would illustrate a cost approximately 9 to 15% of the entire deck. For comparison, it was assumed all decks were similar and took into consideration the 10.42% reduction in thickness and the initial cost of the deck will decrease around 1%. Performing both methods showed that the present worth percentage at the end of the life cycle of solid stainless steel was lower than any other material.

Table 7 compares the initial cost of new bridges of different types of deck reinforcement along with the life cycle cost. Bergmann et al. (2007) assumed that the present worth of deck replacement and 100-year life cycle costs 25% for related costs of replacement, and the 100-year life cycle cost assumes replacement with identical deck design at end of each life span and the FRP values assume equivalent linear quantities with all FRP bars one (1) size larger than steel bars (2007). Based on the results, despite the initial cost of solid stainless and EnduraMet®32 stainless steel, both present worth and life-cycle cost of the two materials is lower than every other reinforcement alternatives for the deck.

In conclusion, the use of all three stages illustrates the savings of stainless steel being incorporated later in the funding. There may be an increase in initial costs but the reward would be beneficial to the owner and the company when there are no major replacements needed over a long period of time. The use of this material can be favorable for the economy, society and the environment surrounding it.

Table 7: Initial cost and life-cycle costs of new bridges with various CCR in deck (Bergmann et al. 2007)

Reinforcing Type	ECR/ galvanized	MMFX2	FRP	Solid Stainless	EnduraMet®32 Stainless
Initial deck cost	100%	103%	106%	112%	106%
Estimated life (years)	40	50	65	100	100
Presented worth of deck replacement at end of life	26.04%	18.12%	10.35%	2.77%	2.10%
100 year life cycle cost as a percentage of initial cost of ECR deck	130.22%	121.12%	115.21%	114.77%	108.62%

Chapter 5: Summary, Recommendations and Future Work

This report provided critical information on the current state-of-the-practice and art of using alternate materials (often referred to as corrosion resistant rebar, CRR) and strategies to minimize the issue of corrosion. The main focus of the study was to explore the efficacy of stainless steel rebar such that SHA can have enough information to make a decision as to whether or not they would be interested in changing from traditional strands to stainless steel rebar and/or strands for various projects. A national survey with 1 international respondent was created and disseminated to various DOT personnel, precasters and mill representatives to gain information on various practices for addressing cracking and corrosion as a result of cracking in addition to familiarity of stainless steel in various projects. This synthesis study provided background information on various case studies for which stainless steel was used, general information about alternative materials with particular focus on the availability of stainless steel, and detailed information from stainless steel manufacturers to assist in the decision-making process for SHA regarding this matter. Life-cycle cost analysis (LCCA) case studies are presented as examples for SHA to ascertain the feasibility of deploying stainless steel in a project. Moreover, companies that specifically melt and manufacture stainless steel in the United States have been identified in this report.

One way to address corrosion is to first address the issue of cracking, especially in prestressed structures. From the survey results, it was determined that the highest recommended strategies to minimize cracking of prestressed, precast elements were to minimize curing times and use alternative curing methods. The most used or recommended strategies to prevent corrosion of reinforcement in bridge elements was reported to be through using epoxy-coated rebar, lowering the permeability of concrete and increasing the clear cover depth. Some other examples include using High Performance Concrete (HPC or higher strength concrete as indicated in the survey) to reduce cracking of bridge decks by reducing heat of hydration and slowing strength gain. However, fifty-four percent (54%) of the respondents would not pay to use stainless steel on a project. It was expressed from the survey that stainless steel should only be used for projects that require a larger quantity of reinforcement because of its high price. Nevertheless, the overall investment in stainless steel specifically over the other CRR for its life-cycle performance can outweigh the higher initial costs as presented by the life-cycle cost analysis (LCCA) example estimates presented. The Appendices include supplemental information gathered from the survey and manufacturers' information.

Future work includes supporting experimental testing of rebar to validate data provided by the stainless steel suppliers should SHA want to conduct their own tests, especially as it relates to assessing ductility and ultimate strengths. Parametric studies can also be conducted to look at the optimal stainless steel rebar sizes and design options that can be used on a particular project.

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Appendices

Appendix A: Survey

Performance Evaluation Survey For Quality Control And Quality Assurance (QA/QC)

SECTION A - PBES PRODUCTION PRACTICES

2 / 3 67%

***1. Which best describes your occupation and years of experience?**

	<5 years	5-10 years	10-20 years	>20 years
Consultant				
Industry/Practitioner				
Academic/Research Engineer				
Other				

Which state do you currently work (e.g. Maryland)?

***2. What would you recommend to minimize cracking of precast elements? Rank your top 8 choices (Scale: 1=low and 8=high).**

	Strategy Recommended	Rank Effectiveness (Scale 1-8)	Rank Financial Benefit (Scale 1-8)
a. Specify maximum cementitious material content			
b. Specify maximum concrete compressive strength			
c. Specify maximum concrete temperature			
d. Specify maximum slump			
e. Use evaporation retardants			
f. Specify minimum curing times			

g. Use of curing method			
h. Use of handling methods			

i. In addition, what do you see as the biggest barrier or problem with QA/QC of PBES?

***3. What strategies are you currently using or recommend to prevent corrosion of reinforcement in bridge elements? Rank your top 10 choices (Scale: 1=low and 10=high).**

	Strategy Used or Recommended	Rank Effectiveness (Scale 1-10)	Rank Financial Benefit (Scale 1-10)
a. Low-permeability concrete			
b. Corrosion inhibitor			
c. Epoxy-coated reinforcement			
d. Fiber-reinforced polymer			
e. Metallic-coated reinforcement			
f. Stainless steel			
g. Other corrosion-resistant			
h. High strength concrete			
I. Increasing clear cover distance			
j. Protective barriers			

k. Please describe the specific problem and the solution was to overcome the problem.

***4. Have you ever experienced any camber problems with prestressed concrete bridge beams that are often beyond normal construction tolerances?**

YES NO

State the typical construction tolerances used and could strand arrangement resulting in problems. Specifically, if two beams have identical number of strands and center of gravity of strands, can the placement of strands within the unit resulting in camber issues?

***5. Do you use a blend of lightweight and normal weight aggregates to achieve the desired density of concrete for your prestressed bridge beams?**

YES NO

If so, do you experience more severe camber problems than using normal weight concrete?

***6. What types and sizes of members (such as box beams, cored slabs, AASHTO girders, bulb tees, etc.) are more prone to cause camber-related problems in your experience?**

Prev Next

Performance Evaluation Survey For Quality Control And Quality Assurance (QA/QC)

SECTION B - MATERIALS

3 / 3		100%

7. Please respond to this question based on your experience with stainless steel bars/strands in the United States?

	Convenient	Neutral	Difficult	Not Applicable
a (i). Availability of stainless steel bars/strands				
ii) Stainless steel availability domestically				
b. Installation process				
c. Combination of stainless steel with conventional steel rebar				
d. Preferred over hyper-dense impermeable concrete mixes such as silica fume blends				

e. Please describe the specific problem and what the solution was to overcome the problem.

8. Would you pay to use stainless steel in a project?

YES NO

Do you feel that the benefits of using stainless steel overshadows the cost? What kind of cost differential has been experienced?

9. If you have used or know someone who has used either stainless steel rebar or strands, then list the company for which the materials were procured and your familiarity with the product. Feel free to also elaborate on any other issues or challenges experienced when using this material.

10. Please enter your contact information. Thank you.

E-mail address

Phone (mobile)

Phone (work)

Name of company

Prev Submit

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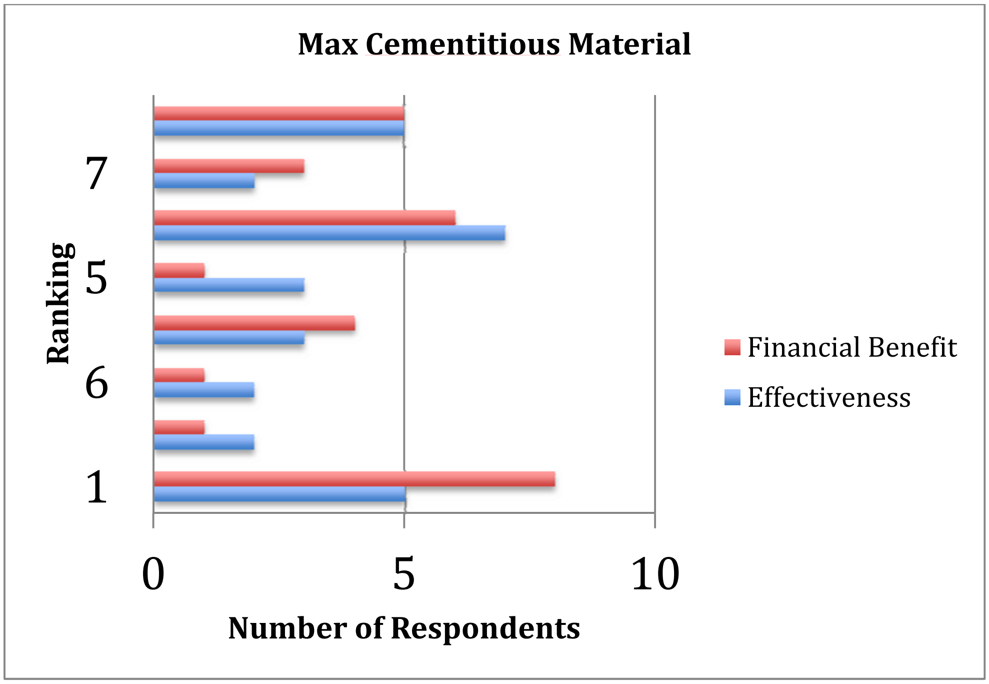
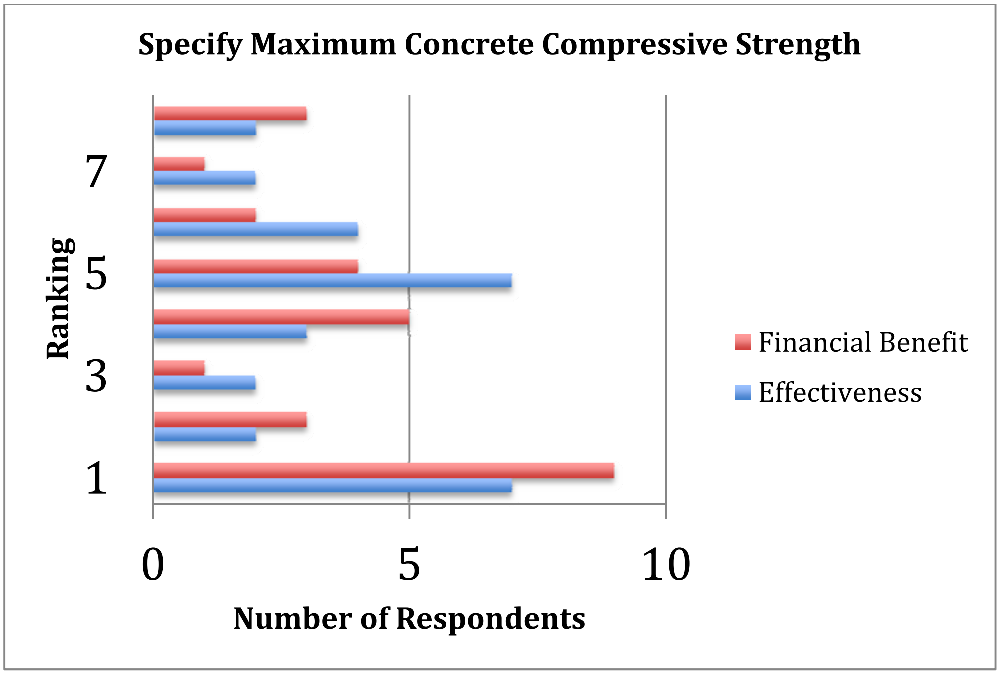
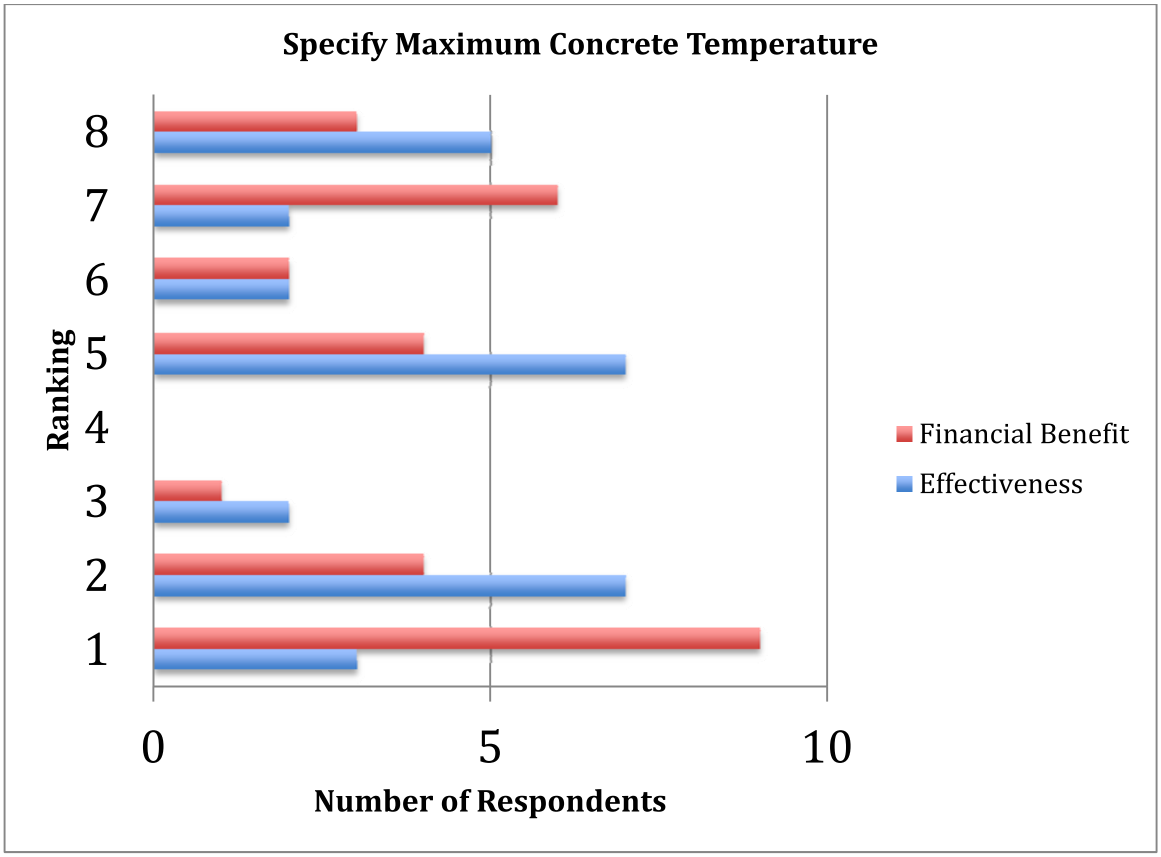
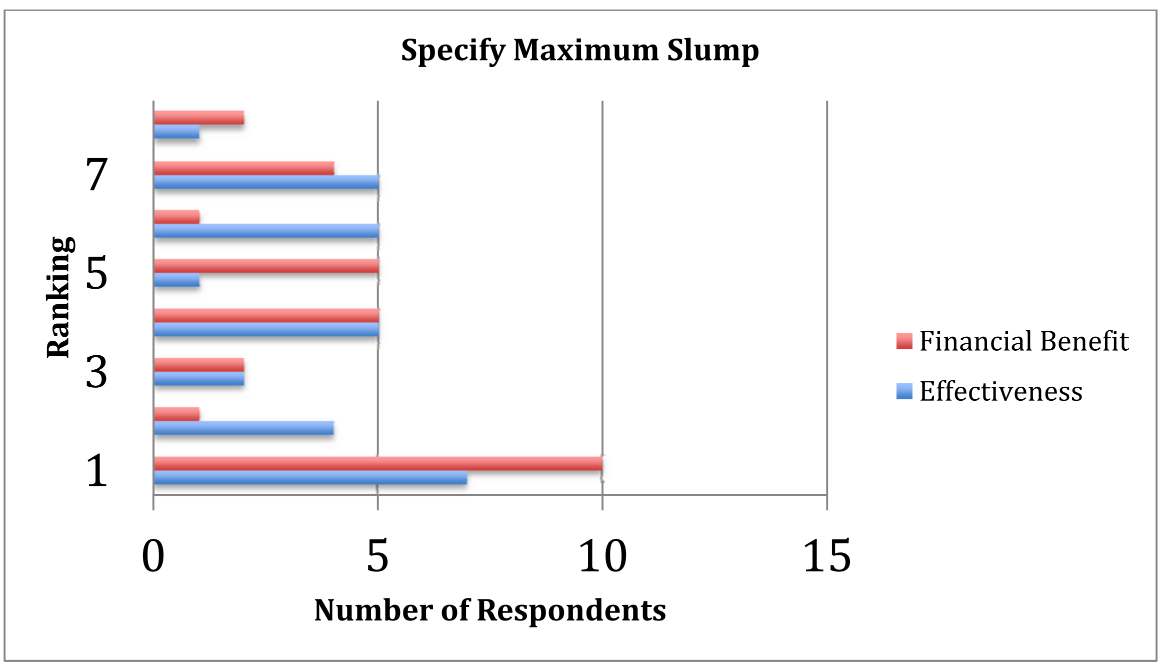
Appendix B: Additional Survey Data

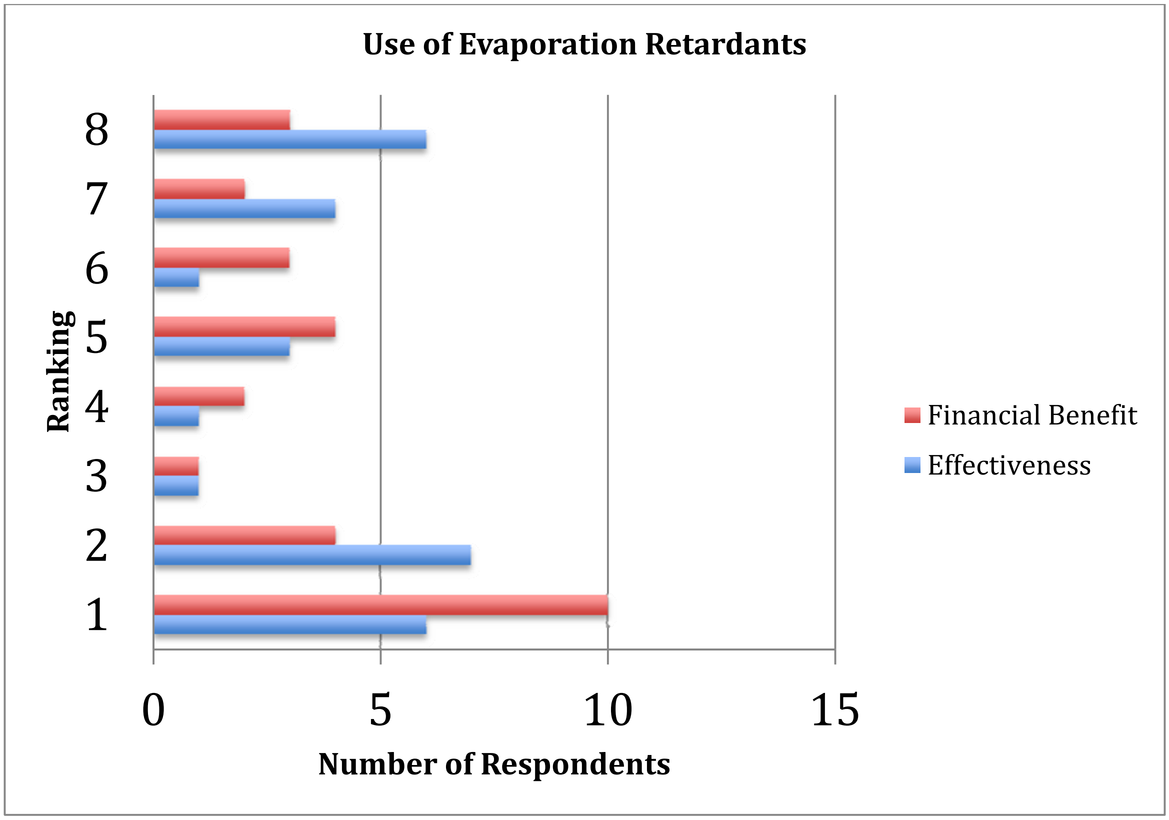
Question 2 Rankings: What would you recommend to minimize cracking of precast elements? Rank your top 8 choices (Scale: 1=low and 8=high)

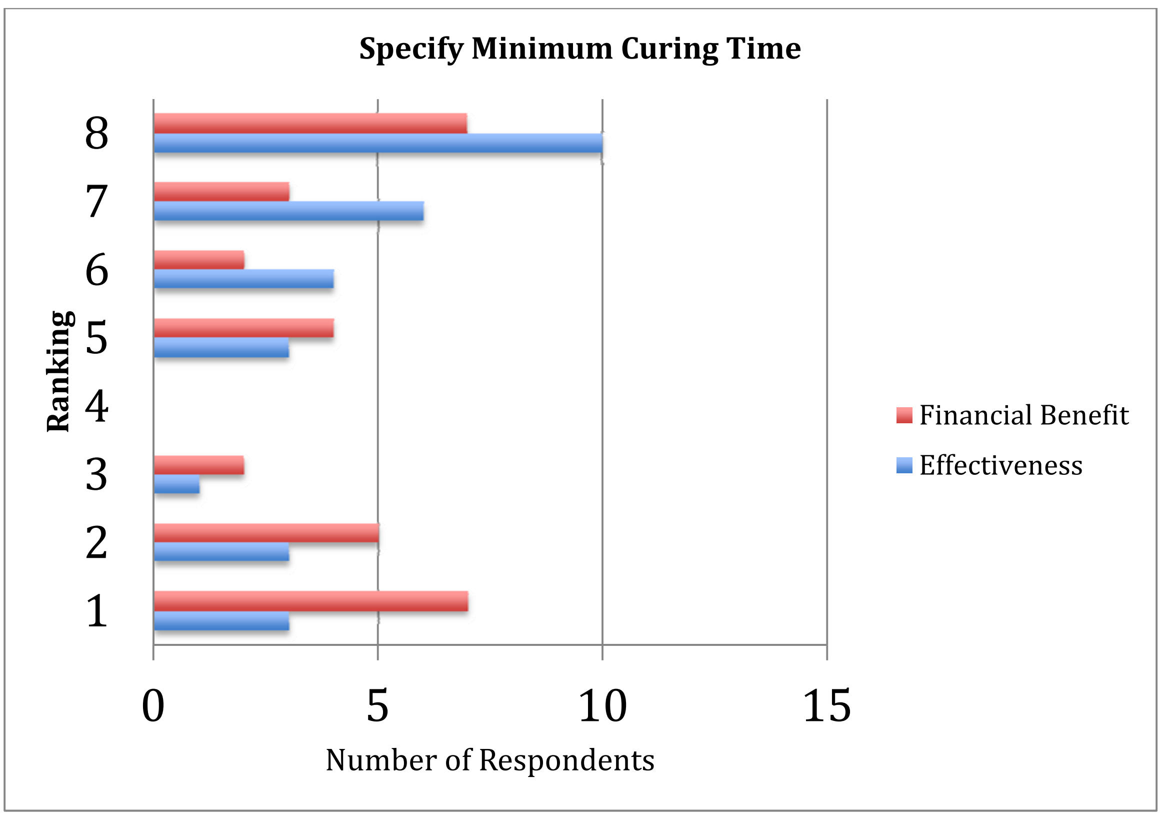


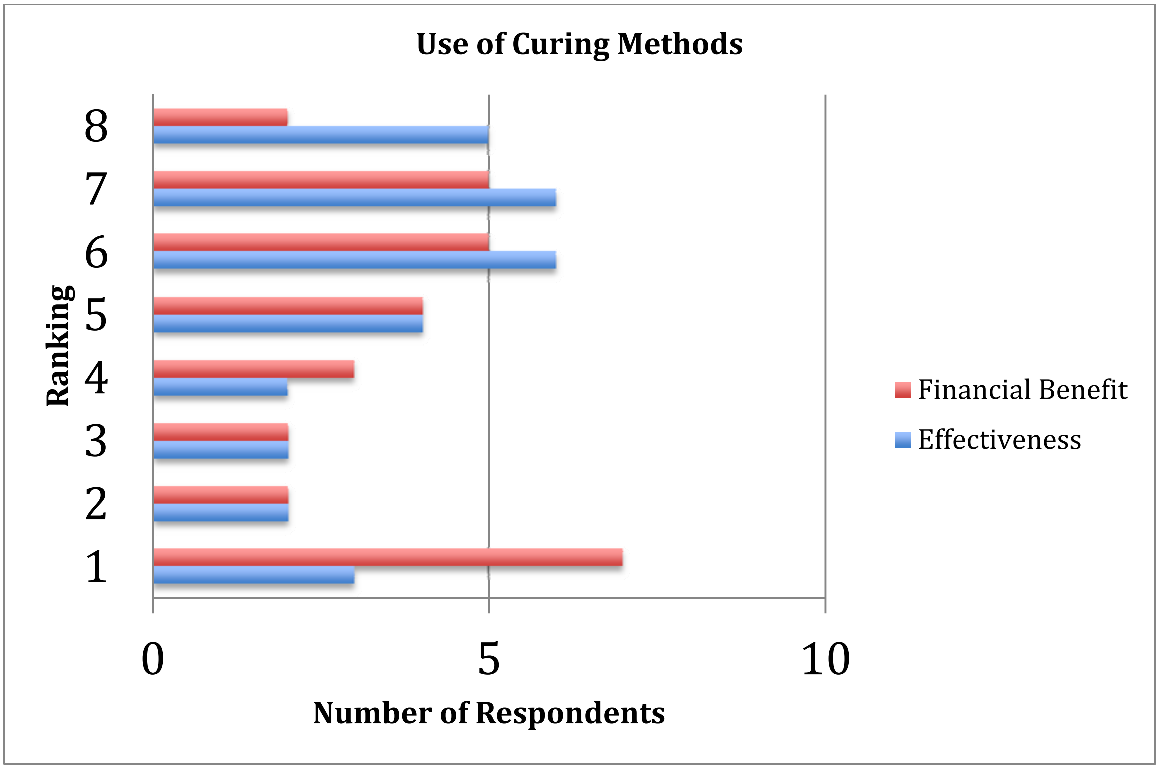


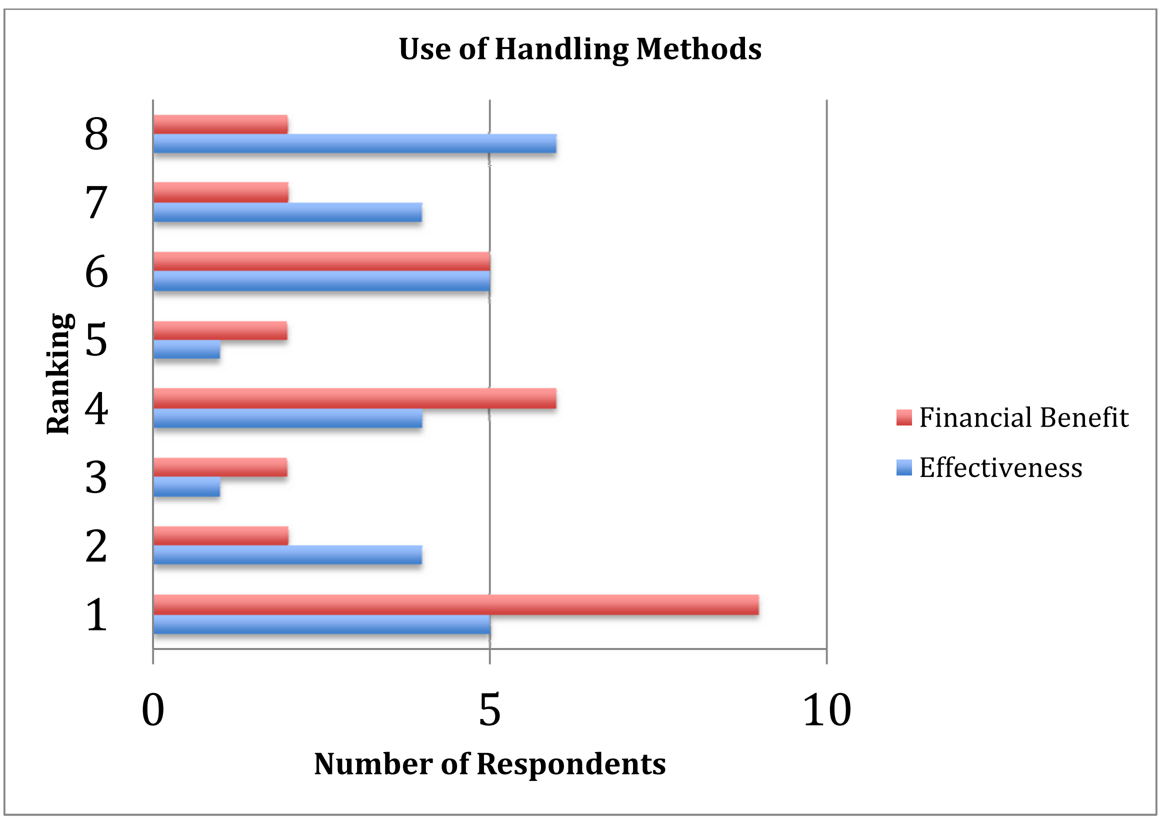

Specify Maximum Concrete Temperature
Ranking
8
7
6
5
4
3
2
1
0
5
10
Number of Respondents
Financial Benefit
Effectiveness


Specify Maximum Slump
Ranking
7
5
3
1
0
5
10
15
Number of Respondents
Financial Benefit
Effectiveness

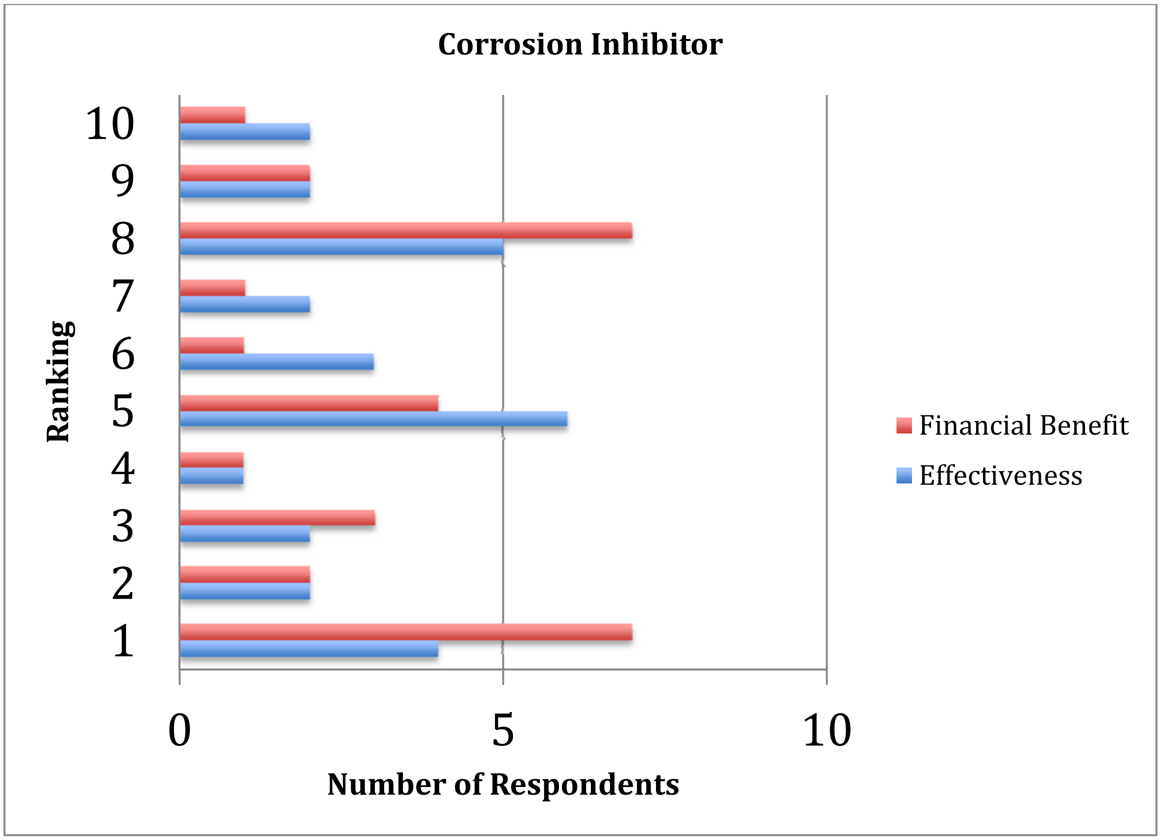

Use of Evaporation Retardants
Ranking
8
7
6
5
4
3
2
1
0
5
10
15
Number of Respondents
Financial Benefit
Effectiveness

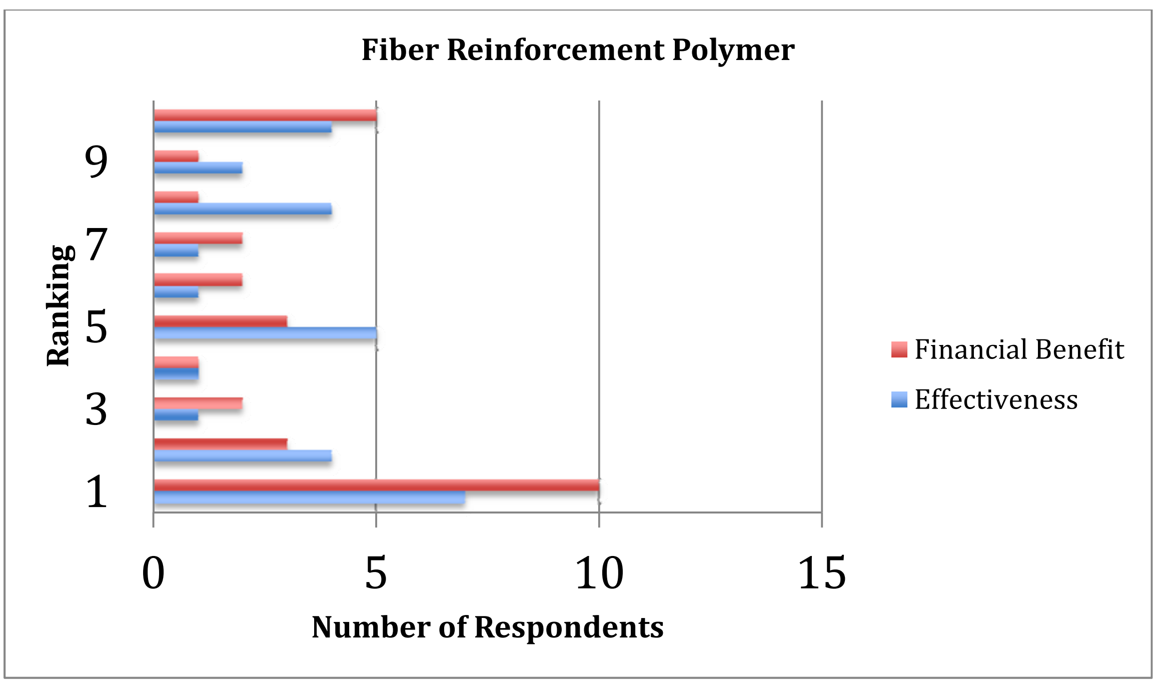

Specify Minimum Curing Time
Ranking
8
7
6
5
4
3
2
1
0
5
10
15
Number of Respondents
Financial Benefit
Effectiveness

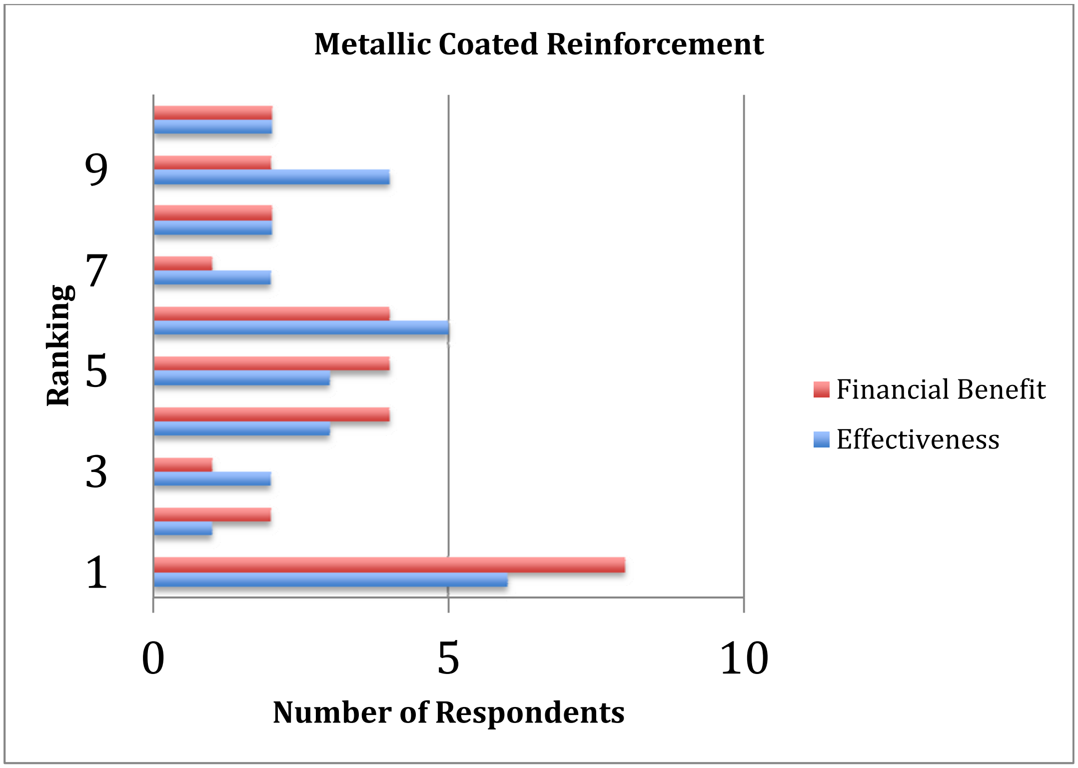

Use of Curing Methods
Ranking
8
7
6
5
4
3
2
1
0
5
10
Number of Respondents
Financial Benefit
Effectiveness


Use of Handling Methods
Ranking
8
7
6
5
4
3
2
1
0
5
10
Number of Respondents
Financial Benefit
Effectiveness

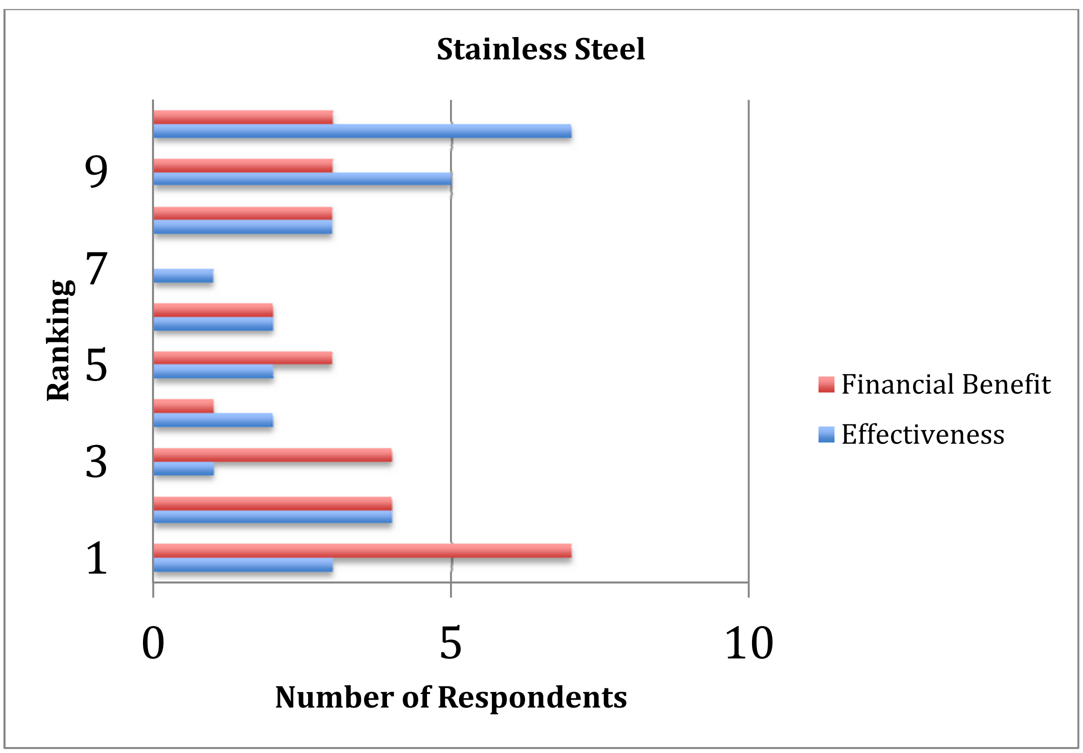
Question 3 Rankings: What strategies are you currently using or recommend to prevent corrosion of reinforcement in bridge elements? Rank your top 10 choices (Scale: 1=low and 10=high).



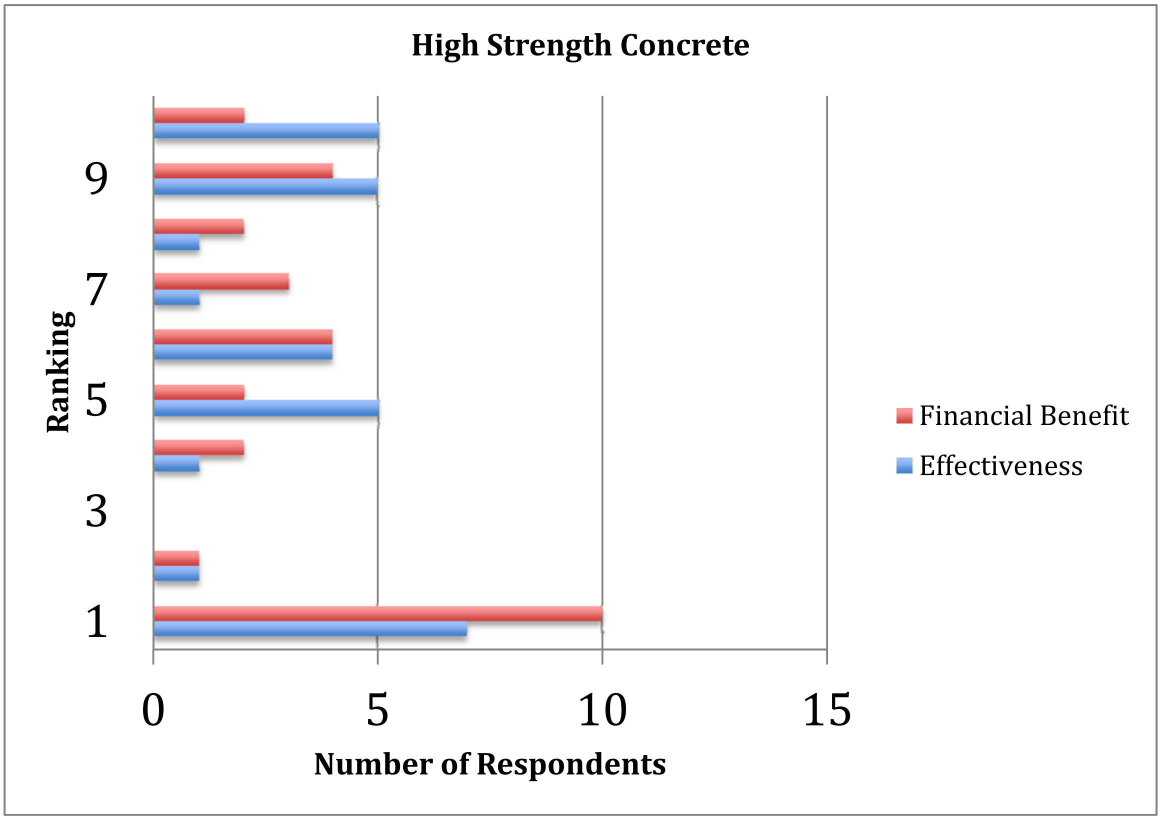




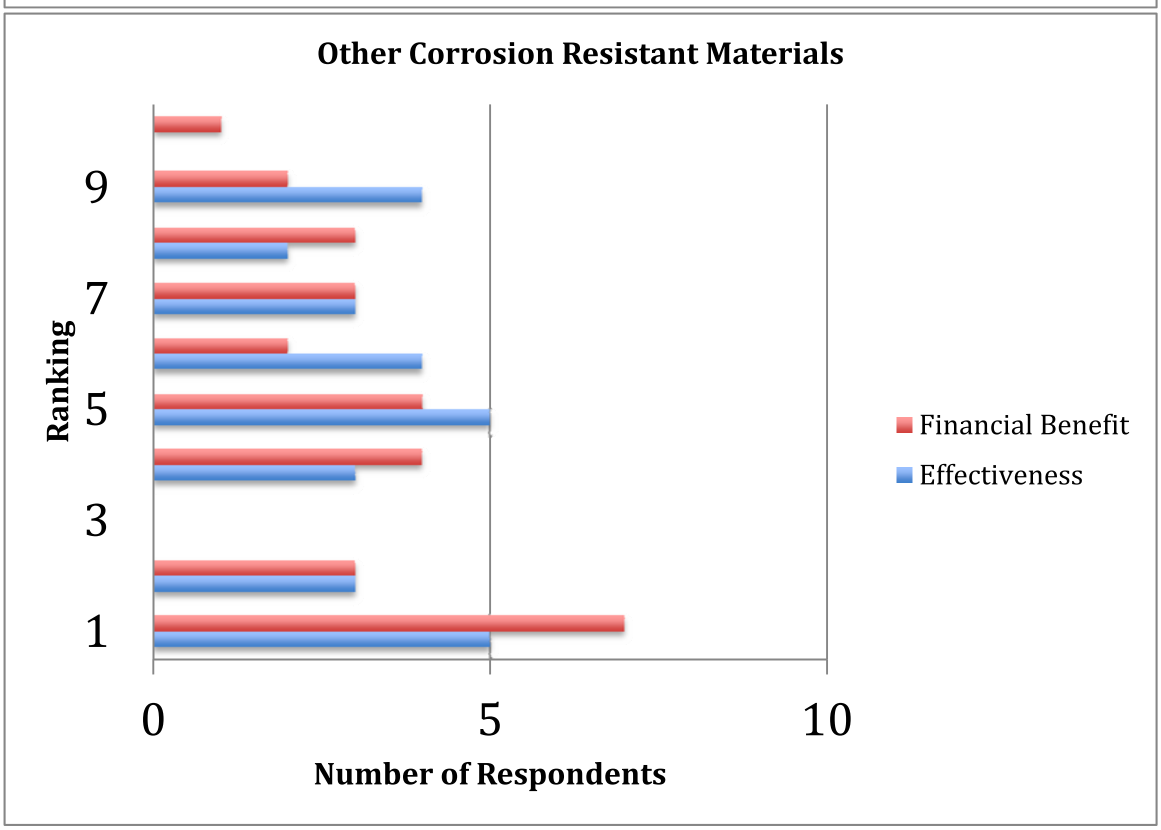
Metallic Coated Reinforcement
9
7
5
3
1
Ranking
0
5
10
Number of Respondents
Financial Benefit
Effectiveness



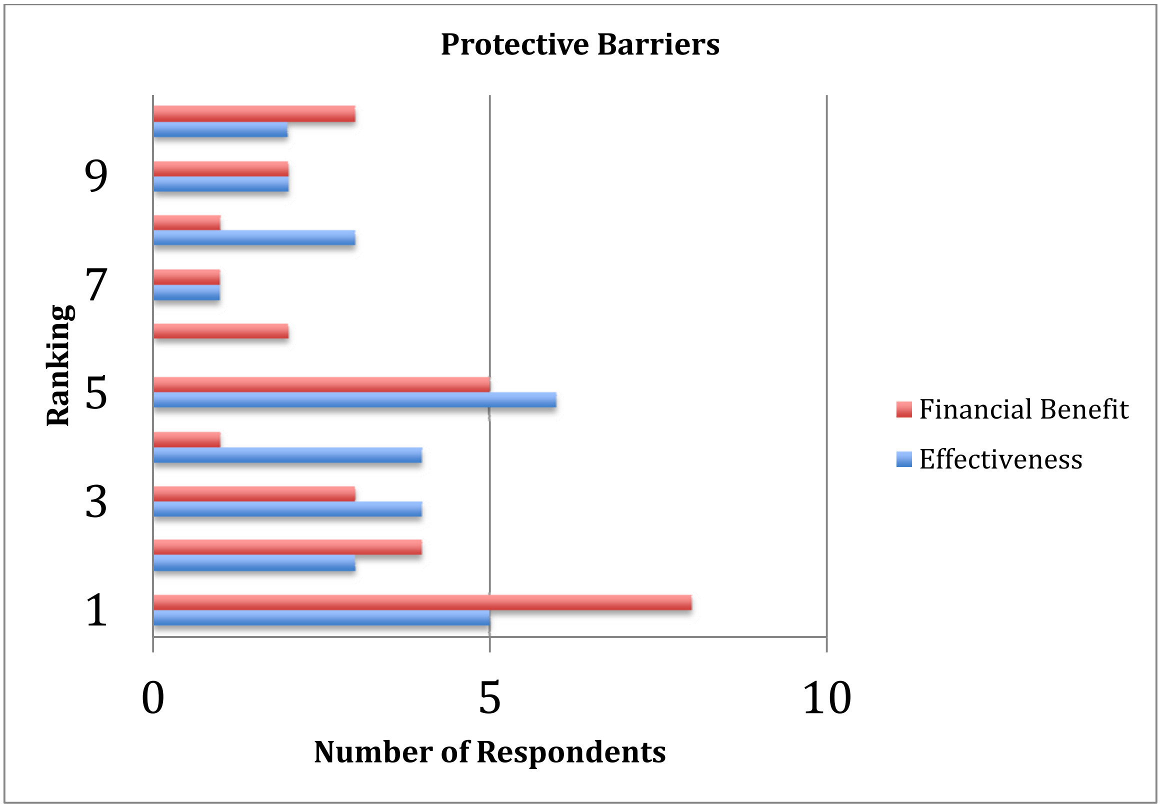
Stainless Steel
9
7
5
3
1
Ranking
0
5
10
Number of Respondents
Financial Benefit
Effectiveness



High Strength Concrete
Ranking
9
7
5
3
1
0
5
10
15
Number of Respondents
Financial Benefit
Effectiveness



Other Corrosion Resistant Materials
Ranking
9
7
5
3
1
0
5
10
Number of Respondents
Financial Benefit
Effectiveness



Question 9

If you have used or know someone who has used either stainless steel rebar or strands, then list the company for which the materials were procured and your familiarity with the product. Feel free to also elaborate on any other issues or challenges experienced when using this material.

- North American Stainless, 6870 Highway 42, East Ghent, KY 41045
- Salit Specialty Rebar, 3235 Lockport Road, Niagara Falls NY 14305
- CMC, 10320 South Medallion Drive, Cincinnati, OH 45241

Appendix C: Manufacturer Data

NAS

NORTH AMERICAN STAINLESS

To our customers:

North American Stainless (NAS) is prepared to certify that all the stainless steel produced by NAS is originally melted at its Ghent, Kentucky USA works, thus all stainless steel it produces has the status of U.S. and NAFTA origin.

Pat Feeley
V.P. Commercial
North American Stainless (NAS)

NORTH AMERICAN STAINLESS
Pricing Extras
Distribution Only
EFFECTIVE WITH SHIPMENTS: May 1, 2014

ITEM EXTRAS

Small Coil (100 - 150 PIW)	$3.00	(<100 PIW must go through warehouse)
Suitable For Buffing Quality 24" – 60"	$5.00	*Buffing quality not guaranteed
PED (All Finishes)	$3.00	+ 2 additional weeks lead time, if outside testing is required.
Slow Anneal	$5.00	+ 2 additional weeks lead time
Charpy Testing	$3.00	+ 2 additional weeks lead time
Outside Processing – Stretcher Level	$10.00	+ 2 additional weeks lead time
Outside Processing – Slitting	Inquire	

SPECIAL CHEMISTRY EXTRAS
NICKEL (304 AND 304L)

8.5% MIN	$3.00
9.0% MIN	$5.75
9.5% MIN	$8.75

304 H — No adder- QC can add filter to format
Chem and grain size cert on discrete plate
Chem only on CR and CMP

COLD ROLL ODD-WIDTH SLITTING ADDERS
Coils (or cuts) that will be produced across the width of the coil

Less than POC order qty:
1 coil - $1.50/cwt
2-3 coils - $3/cwt
4-5 coils - $5/cwt
6 or more - Inquire

POC order qty (increments):
1 coil – No adder
2-3 coils - $1.50/cwt
4-5 coils - $3/cwt
6 or more – Inquire

CR/HR Coil Mill Edge -$1.50/cwt deduct

HOT ROLL ODD-LENGTH CUTTING ADDER
$5/cwt

PMP Rolled-Edge (mill edge) - $4/cwt deduct

SHIPPING TOLERANCE PER ITEM

< 100,000#	+ / - 10%
≥ 100,000#	+ / - 5%

DOUBLE-SIDED POLISH

Current Polish Rate for Ordered Finish x 2.5 added after the discount (POC min/increment)

NORTH AMERICAN STAINLESS
Pricing Extras
Distribution Only
EFFECTIVE WITH SHIPMENTS: May 1, 2014

PACKAGING EXTRAS

CTL SKID
72” – 168” $40.00
168.1” – 360” $150.00

COIL SKID $15.00

CMP AND CR CUT TO LENGTH EXTRAS

USS GAUGE	THICKNESS ORDER RANGE	WIDTH	LENGTH	CWT
3/8” – 14	.3900 - .0700	36” – 60”	72” – 360”	$3.00
15 – 18	.0699 - .0440	36” – 60”	60” – 240”	$3.25
19 – 20	.0439 - .0330	36” – 60”	60” – 240”	$3.75
21	.0329-.0300	36” – 60”	60” – 240”	INQUIRE
22 – 24	.0299 - .0220*	36” – 60”	60” – 240”	INQUIRE
25 – 26	.0219 - .0160*	36” – 60”	60” – 240”	INQUIRE

*22-26ga includes a $3/cwt adder for trimming. (Coils have to be trimmed prior to being CTL)

- CTL orders require a min order quantity of 15,000 lbs for a maximum of 3 different lengths
    - Note, the min for any one length is 4,000 lbs

PVC EXTRAS

GAUGE	Black/White (Standard)	Clear	Laser	Nitto Laser 3100H5	Blue Nitto 224
NAS Coating Code	**B**	**D**	**L**	**Z**	**H**
7	.0335	.0356	.0381	.0392	.0523
8	.0350	.0375	.0404	.0416	.0570
10	.0370	.0400	.0436	.0451	.0638
11	.0390	.0424	.0464	.0481	.0693
12	.0420	.0459	.0505	.0525	.0767
13	.0455	.0500	.0554	.0577	.0860
14	.0510	.0564	.0629	.0656	.0996
16	.0590	.0658	.0740	.0775	.1203
18	.0680	.0766	.0867	.0911	.1446
19	.0735	.0829	.0940	.0988	.1574
20	.0860	.0974	.1110	.1168	.1881
22	.0980	.1121	.1288	.1359	.2238
24	.1180	.1350	.1551	.1638	.2698

- PVC is added to base price of material after discount has been applied.
- For all odd-width quotes, include the PVC in the base price of the master coil (before odd-width calculation).

NORTH AMERICAN STAINLESS
Pricing Extras
Distribution Only
EFFECTIVE WITH SHIPMENTS: May 1, 2014

- NAS can only apply PVC to one-side of material.

TEMPER EXTRAS*

THICKNESS	¼ HARD	½ HARD	¾ HARD	FULL HARD
	125,000 Min Tens.	150,000 Min Tens.	175,000 Min Tens.	185,000 Min Tens.
	36" – 60"	36" – 60"	36" – 60"	36" – 60"
.1450 - .0470	$5.00	$5.00	$5.00	$5.00
.0469 - .0360	$5.00	$5.00	$5.00	$5.00
.0359 - .0240	$5.00	$5.00	$5.00	$5.00
.0239 - .0178	$5.00	$5.00	$5.00	$5.00
.0177 - .0146	$5.00	$5.00	$5.00	$5.00

*Pricing extras for temper products is added after the discount.

NORTH AMERICAN STAINLESS

Material Safety Data Sheet
Stainless Steel

July 2012

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Section 1 – Chemical Product and Company Identification

Manufacturer:	North American Stainless 6870 US 42 East Ghent, KY 41045
Emergency Number:	(502) 347-6650 (502) 347-6111 after 5:00 PM
Product Name:	Stainless Steel Products, All Grades
Description:	Solid material in various forms
Technical Contact:	Environmental, Safety & Health
Date of Revision:	July 25, 2012

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Section 2 – Composition / Ingredients

Note: Steel products in their natural state do not present an inhalation or contact hazard, however operations such as burning, welding, sawing, brazing and grinding my release fumes and or dust, which may present health hazards. There is not an American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) or OSHA exposure limit (PEL) established for steel.

Component	CAS #	Percent	OSHA PEL(mg/m^3)	ACGIH TLV (mg/m3)
Iron	7439-89-6	45 – 90	10 mg/ m^3 Iron Oxide – Fume	10 mg/ m^3 Iron Oxide – Dust & Fume
Nickel	7440-02-2	0 – 40	1 mg/m^3, Metal, soluble & insoluble compounds	1.5 mg/ m^3 Metal 0.1 mg/ m^3 Soluble compounds 0.2 mg/ m^3, Insoluble compounds
Chromium	7440-47-3	10.5 – 30	1 mg/ m^3, Metal & insoluble salt 0.5 mg/m^3, Cr (III) 5 μg/m^3, Cr (VI) 2.5 μg/m^3 Action Level Cr (VI)	0.5 mg/m^3 Metal and Cr (III) 0.05 mg/m^3, Cr (VI) & water soluble compounds 0.01 mg/m^3, Cr (VI) Insoluble compounds
Manganese	7439-96-5	0 – 15	5 mg/m^3 (ceiling)	0.2 mg/m^3
Molybdenum	7429-98-7	0 – 5	5 mg/m^3 Soluble compounds as MO 15 mg/m^3 Total dust	5 mg/m^3 Soluble compounds as MO 10 mg/m^3 Insoluble compounds as MO
Copper	7440-50-8	0 – 5	0.1 mg/m^3 Fume 1.0 mg/m^3 Dust & Mist	0.2 mg/m^3 Fume 1.0 mg/m^3 Dust & Mist
Silicon	7440-21-3	0 – 3	15 mg/m^3 Total dust 5 mg/m^3 Respirable dust	10 mg/m^3 Total dust
Aluminum	7429-90-5	0 – 1	15 mg/m^3 Metal & Total dust 5 mg/m^3 Respirable dust	1 mg/m^3 Respirable dust 5 mg/m^3 Welding fume
Cobalt	7440-48-4	0 – 1	0.1 mg/m^3 Metal, Dust & Fume	0.02 mg/m^3 Metal, Dust & Fume
Vanadium	1314-62-1	Trace	0.5 mg/m^3 (ceiling) Vanadium Pentoxide dust 0.1 mg/m^3 (ceiling) Vanadium Pentoxide fume	0.05 mg/m^3 Vanadium Pentoxide

Tungsten	7440-33-7	Trace	15mg/m3 Total Dust 5 mg/m3 Respirable dust	1.0 mg/m3 3 mg/m3 STEL Soluble 5.0 mg/m3 10 mg/m3 STEL Insoluble
Tantalum	7440-25-7	Trace	5 mg/m3 Metal & Oxide dust 10 mg/m3 STEL	5 mg/m3 Metal & Oxide dust
Titanium	7440-32-6	0 – 1	15 mg/m3 Titanium Dioxide total dust	10 mg/m3 Titanium Dioxide total dust
Lead	7439-92-1	Trace	0.05 mg/m3	0.05 mg/m3

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Section 3 – Hazard Identification:

General Hazard Statement: Solid metallic products are classified as "articles" and are not hazardous materials in their solid form under the definitions of the OSHA Hazard Communication Standard (29 CFR 1910.1200). Articles manufactured from these solid products are generally considered non hazardous as well. However some hazardous elements of these products can be emitted under certain processing conditions such as but not limited to: burning, melting, cutting, brazing, grinding, machining, milling, and welding.

Primary route of entry: Inhalation of dust or fume during welding, burning, melting, cutting, brazing, grinding, machining, milling, welding and other operations.

Effects of Overexposure: Stainless, as a solid, is not toxic and presents no health hazard. Overexposure to dusts and or fumes which may result during processing can pose health hazards as defined below

Acute Effects of Overexposure:

Inhalation: Inhalation of high concentrations of fumes or dusts may result in irritation and or sensitization of the respiratory track, nasal irritation, and metal fume fever.
Eyes: Exposure to fumes and dusts can cause irritation and or sensitization and conjunctivitis.
Skin: Contact with dusts may cause irritation or sensitization leading to dermatitis.
Ingestion: Nausea or vomiting may result from ingestion of dusts

Chronic Effects of Overexposure:

Inhalation: Prolonged inhalation of dust or fume may cause lung, central nervous system, liver, kidney, and nasal cavity damage.
Eyes: Prolonged exposure to fumes and dusts can cause severe irritation, and or sensitization and conjunctivitis.
Skin: Prolonged contact with dusts may cause severe irritation or sensitization leading to dermatitis.
Ingestion: Nausea or vomiting may result from ingestion of dusts
Eye inflammation

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Section 4 – First Aid Measures:

Eye Contact: Wash with copious amounts of water for 15 minutes to ensure that no articles remain in the eye. Seek medical advice if irritation persists
Skin Contact: If irritation develops, wash skin thoroughly with soap and water. Seek medical attention, if necessary.
Inhalation: Remove from dusty area to fresh air: if discomfort persists, consult physician.
Ingestion: If significant amounts of dusts are ingested consult physician.

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Section 5 - Fire and Explosion Information:

Flash Point (°F):	N/A
Method Used:	N/A
Auto-Ignition Temperature (°F):	N/A
Flammability Limits (%/Vol):	
LEL: (Lower Explosive Limit)	N/A
UEL:(Upper Explosive Limit)	N/A
Flammability Classification	N/A

Hazardous Combustion Products: Not applicable for solid formed alloy. Toxic metal and metallic oxide fumes may be evolved from fires involving finely divided alloy.

Extinguishing Media: For solid formed alloys, as appropriate for surrounding fire. A fire involving finely divided alloy should be treated as Class D Combustible metal fire. Fire should be extinguished by a properly trained and experienced firefighter. Proper care should be taken in applying extinguishing agent.

Special Fire Fighting Instructions: For solid formed alloy, as appropriate for surrounding fire. Positive pressure SCBE and structural firefighter's protective clothing should be used at a minimum for surrounding fire.

Unusual Fire and Explosion Hazards: Solid formed alloy does not constitute a fire or explosion hazard. However, finely divided, suspended particulates may present a fire and explosion hazard in the presence of an ignition source.

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Section 6 – Accidental Release Measures:

Solid Form: N/A
Dust Form: Shut off ignition source; no flares, smoking or flames should be in or near hazard area. Do not touch or walk through spilled material. Clean up using methods which avoid dust generation. Compressed air should not be used. During cleanup avoid inhalation and skin and eye contact. Provide local exhaust or dilution ventilation as required
Disposal: Dispose of in accordance with all applicable federal, state and local regulations.

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Section 7 – Handling and Storage:

Handling: Avoid breathing of and contact with fumes and dusts during processing. No specific requirements for solid formed steel product
Storage: Keep away fro incompatible materials (section 10)

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Section 8 – Exposure Control and Personal Protection:

Engineering Controls: Local and or general exhaust ventilation should be used to keep worker exposure below applicable exposure limits (section 2) during welding, brazing, grinding, machining, and other processes which may generate airborne contaminants.
Respiratory: NIOSH / MSHA – approved dust/mist/fume respiratory should be used during welding, burning, and grinding operations, if applicable exposure limits (section 2) are exceeded
Gloves: Suitable for protection against physical injury and skin contact during handling and processing.
Eyes: Safety glasses or goggles should be worn when there is probability of flying particles or elevated levels of dust or fume.

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Section 9 - Physical and Chemical Properties:

Boiling Point (°F):	N/A
Vapor Pressure (mmHg @ 20°C):	N/A
Vapor Density (AIR=1):	N/A
Melting Point	2500 – 2800 °F
Solubility in Water:	Insoluble
Viscosity:	N/A
Specific Gravity (H_20=1):	7.65 to 7.94
Percent Volatile by Volume:	N/A
Evaporative rate (Ethyl Ether = 1):	N/A
pH Information:	N/A
Appearance and Odor:	Odorless solid silver-gray metallic

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Section 10 – Stability and Reactivity Data:

STABILITY (Conditions to avoid): Stable under normal conditions of transport, storage and use for solid formed product
INCOMPATIBILITY (Material to avoid): Oxidizers. Reacts with strong acids to form explosive hydrogen gas.

HAZARDOUS DECOMPOSITION PRODUCTS: During certain operations such as welding, burning, melting or hot rolling, metal fumes may be generated. Hexavalent chromium which is a suspect carcinogen may result from pickling of stainless.

HAZARDOUS POLYMERIZATION: Will not occur.

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Section 11 – Toxicological Data:

Iron: Excessive exposure of eyes to airborne iron dust can cause conjunctivitis, choroiditis, and retinitis. Chronic inhalation of high concentrations of iron oxide fume or dust may result in the siderosis (benign pneumoconiosis).
LD_{50} (oral rat) – 30gm/kg; LC_{50} – No Data
Nickel: The most common effect resulting from exposure to nickel compounds is "nickel itch", a form of dermatitis in sensitized individuals. Nickel sensitivity, once acquired, may persist indefinitely.
LD_{50} = 50 mg/kg mouse – intravenous. LC_{50} – No Data
Carcinogenicity: NTP- Reasonably anticipated to be carcinogenic; IARC- Group 1 (there is sufficient evidence for carcinogenicity in humans) and 2B (agents which are possibility carcinogenic to humans); OSHA – Not regulated; ACGIH – A5 (not a suspected human carcinogen)
Chromium: Health hazards associated with exposures are dependent upon its oxidation state. Suspect carcinogen and tumorigen. Dermatitis may result from exposure to chromium fumes.
LD_{50} (Oral) – No Data; LC_{50} – No Data
Carcinogenicity: Chromium metal and trivalent chromium compounds are not classifiable as human carcinogens. Hexavalent Chromium (produced by welding, torch cutting, brazing and possibly grinding) is a confirmed human carcinogen. NTP – Group 1 (known to be carcinogenic); IARC- Group 1 (there is sufficient evidence for carcinogenicity in humans) and 2B (agents which are possibility carcinogenic to humans); ACGIH – A1 (confirmed human carcinogen)

Manganese: Can affect central nervous system, including languor, sleepiness, weakness, emotional disturbances, spastic gait, recurring leg cramps, and paralysis. Upper respiratory system damage may result from inhalation of fume and dust.
LD_{50} (Oral - Rat) – 30 gm/kg; LC_{50} – No Data
Molybdenum: Irritation of nose and throat, weight loss and digestive disturbances in animals. Can cause joint pains in the hands, knees, and feet. No industrial poisonings have been reported.
LD_{50} (Oral) – No Data; LC_{50} – No Data
Copper: May be responsible for one form of metal fume fever. Metal fume fever's symptoms include cough, headache, fever, nausea, chilling, pain in muscles and joints, and metal taste in mouth. This condition is usually transitory lasting one day or less. Chronic exposure may also result in Wilson's Disease (characterized by hepatic cirrhosis, brain damage, demyelination, renal disease, and copper deposition in the cornea.
LD_{50} (Oral) – No Data; LC_{50} – No Data
Silicon: Is an inert material which does not appear to have the ability to cause fibrosis in lung tissue. Silicon may cause chronic respiratory effects.
LD_{50} (Oral-Rat) – 3160 mg/kg; LC_{50} – No Data
Aluminum: Inhalation of finely divided aluminum and aluminum oxide powder can cause pulmonary fibrosis and lung damage.
LD_{50} (Oral) – No Data; LC_{50} – No Data
Cobalt: Exposure to high levels of cobalt can result in lung and heart effects and dermatitis. An experimental carcinogen.
LD_{50} (Oral) – No Data; LC_{50} – No Data
Carcinogenicity: IARC – possibly carcinogenic to humans. ACGIH – animal carcinogen.
Particulates: Eye and respiratory irritation may occur with exposures to dust.

Medical conditions known to be aggravated by exposure to this material: Persons with lung disorders or diseases or skin disorders may be at added risk as a result of overexposure to this material.

****

Section 12 – Ecological Data:
Not applicable for solid alloy product in its as shipped form. Articles produced from solid product are not an ecological hazard. No information has been found on specific alloy to establish its effect onto the environment if released in a finely divided form. It is believed that finely divided alloy will be hazardous to fish, animals, plants, and the environment. The degree of hazard would depend on the particle size and quantity released. If particle size is small enough, alloy may be ingested by wildlife, with possible toxic effects occurring.

Solid alloy is not expected to migrate easily into soil or ground water. Finely divided alloy can become mobile in water and contaminate soil and ground water. Finely divided alloy may persist in the environment for long periods of time based upon the corrosion resistant, insoluble, and non-biodegradable properties of the alloy. In addition, heavy metals may contaminate the food chain and be consumed by humans

Some alloy components will react with oxygen to form metallic oxides at varying rates. Iron oxidizes most rapidly in moist air. Metallic particulate discharged to a POTW may pass through or contaminate sewage sludge, may interfere with the treatment system process, and may be non compliant with a POTW permit or other regulations.

****

Section 13 – Disposal Data:

If product as shipped becomes a solid waste, it would not be considered a hazardous waste and should be recycled. Product dusts from processing may be classified as hazardous wastes which are defined within 40 CFR 261 as well as state and or local regulation. Solid waste generated from product processing should be classified by a competent environmental professional and disposed, processed, or recycled in accordance with federal, state, and local regulation.

****

Section 14 – Transportation Data:

Hazardous Material Proper Shipping Name:	N/A for solid formed product
Hazard Class:	N/A for solid formed product
Identification Number:	N/A for solid formed product

Note: Stainless steel transported in coiled form is under tension and represents a significant source of potential energy due to the tension induced by coiling; it will uncoil to try to lay flat in a long strip when banding is cut or other forces are released; uncoiling can be sudden and catastrophic and measures should be taken to ensure that uncoiling will not occur.

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Section 15 – Regulatory Data:

SARA Title III Hazard Categorization: Product (dust and fume) is categorized as an immediate (acute) health hazard and a delayed (chronic) health hazard as defined by 40 CFR 370. Product is not categorized as a fire hazard. Product is not categorized as a reactivity hazard. Product is not categorized as a pressure release hazard.

SARA Title III Section 302 Extremely Hazardous Substances (EHS's): None

SARA Title III Section 313 Reportable Substances:

Nickel, Cobalt, Chromium, Aluminum, Manganese and Copper.

CERCLA Hazardous Substance: (If diameter of released particle >10 micrometers)

Nickel – 100 pound threshold
Chromium – 5000 pound threshold
Copper – 5000 pound threshold

TSCA: The components of this product are listed on the Toxic Substance Control Act Inventory.

Pennsylvania R-T-K List:

Aluminum, Manganese, Molybdenum, Nickel, Silicon, Chromium, Cobalt, Copper, and Tantalum.

New Jersey R-T-K Environmental Hazardous Substance List:

Aluminum, Chromium, Copper, Cobalt, Manganese, and Nickel

California Proposition 6e:

Listed possible trace elements know by the state to cause cancer – Arsenic (inorganic), Cadmium, Lead.
Listed possible trace elements know by the state to cause reproductive toxicity – Lead
Listed components known by the state to cause cancer – Nickel, Cobalt (metal powder)
Listed components known by the state to cause reproductive effects – None

****

Section 16 - Additional Information

NFPA Rating: Health: 1	Flammability: 0	Reactivity: 0	
HMIS Rating: Health: 1	Flammability: 0	Reactivity: 0	PPE: B

EPA Hazardous Waste Number: N/A

Note: The percent composition Section 2 reflects the range that is possible within this group of products. These are not the technical specifications for particular product. All grades do not include all hazardous ingredients in section 2.

ABBREVIATIONS / ACRONYMS

ACGIH	American Conference of Governmental Hygienists
CAS	Chemical Abstracts Service
CFR	Code of Federal Regulations
HMIS	Hazardous Materials Information System
IARC	International Agency for Research on Cancer
mg/m^3	Milligrams per cubic meter of air
MSDS	Material Safety Data Sheets
MSHA	Mine Safety and Health Administration
N/A	Not Applicable
NFPA	National Fire Protection Association
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
POTW	Publicly Owned Treatment Work
PPE	Personal Protective Equipment
STEL	Short Term Exposure Limit
TLV	Threshold Limit Value
TWA	Time-weighted Average

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EnduraMet® Solid Stainless Steel Rebar

TALLEY METALS
A Carpenter Company

Talley Metals Technology, Inc., a Carpenter company, produces premium-quality stainless steel bars and high-strength, solid stainless steel rebar.

- Stainless rebar grades:

EnduraMet® 32	EnduraMet 316LN	EnduraMet 2304
EnduraMet 2205	EnduraMet 33	

- Melted and manufactured in the U.S.A. to strict quality standards
- Readily available in lengths up to 40 feet (12.2 meters)
- Sizes #3 through #18 (9.5 mm through 57 mm)*
- Capable of meeting ASTM 955 and BS 6744

** excludes #16*

Talley rebar has been used for concrete reinforcement in a wide range of construction projects requiring long-term resistance from road salt, harsh marine environments, seismic areas, and the concrete itself. Solid stainless steel rebar is superior in corrosion resistance and strength to epoxy coated, SS clad, hot dipped galvanized (HDG), and 9% Cr alloy steel rebar in addition to commonly used carbon steel rebar because of:

- Superior corrosion resistance to chlorides (2000 to 3000 times more resistant than black bar)
- Minimum maintenance requirements
- Durable and self-healing to abrasion and handling damage
- No end capping or field repairs required
- Extensive shelf, storage and service life (100+ years)
- Low magnetic permeability (EnduraMet 32, EnduraMet 33, EnduraMet 2304 and EnduraMet 316LN)
- Competitive cost structure over full-life-cycle cost analysis
- Diverse material selection for possible use in specialized military, scientific and research applications
- Descaled and passivated to enhance corrosion resistance
- Superior ductility

Potential applications for Talley's spiral-ribbed stainless rebar:

- Bridge decks, parapets, sidewalks and pilings
- Barrier and retaining walls
- Anchoring systems
- Magnetic resonance imaging (MRI)
- Chemical plant infrastructure
- Coastal piers and wharves
- Jetties and moorings
- Parking garages

Visit us at www.talley-metals.com

Each bar is coded with the following designation

- T = manufactured by Talley Metals, a Carpenter company
- 2-digit number = bar diameter in mm
- CR = corrosion resistant
- Dots indicate strength level (two dots is highest strength)

ISO 9001:2000

Talley Sales
P.O. Box 2498
Hartsville, SC 29550
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Applications specifically suggested for material described herein are made solely for the purpose of illustration to enable the reader to make his/her own evaluation and are not intended as warranties, either express or implied, of fitness for these or other purposes. There is no representation that the recipient of this literature will receive updated editions as they become available.

NEWS

CARPENTER

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NEW BRIDGE IN BROOKLYN FEATURES 100-YEAR LIFE, STAINLESS REBAR, PRECAST CONSTRUCTION, FAST BUILD, NO TRAFFIC DISRUPTION

NEW YORK, NY (August 12, 2004) - Happiness for a bridge builder in a metropolitan area with chronic traffic congestion is a new bridge that will last a century, require no more than routine inspection during its lifetime, come at a reasonable cost and, during construction, allow residents near the job site to enjoy life without any major inconvenience and motorists to drive by as though nothing were happening.

This is not a dream scenario. All of the above are realistic expectations of the New York City Department of Transportation (NYCDOT) for its newest bridge in Brooklyn and its first federally funded design/build procurement. What's more, the new Belt Parkway Bridge over Ocean Parkway in that heavily traveled part of the borough is to be completed in record time – 290 consecutive days, starting March 1 of this year.

Eyes widened in disbelief when Paul Atkins, P.E., Area Manager of Granite Halmar Construction Co., Inc., Mt. Vernon, NY, told NYCDOT officials that his firm planned to complete the bridge in one construction season, an unusually short duration for a job of this magnitude. Although NYCDOT had set the duration of construction activities as a criterion for selection, most thought that this build pace was too good to be true. Upon careful review of the contractor's proposal, NYCDOT felt this was the way to go.

Furthermore, the general contractor is putting its reputation as well as its fiscal welfare on the line because they have agreed to a bonus/penalty of $85,000 a day based on beating or missing the completion deadline.

The design team led by Granite Halmar; Gannett Fleming Engineers and Architects, P.C., New York, and precast concrete manufacturer The Fort Miller Co., Schuylerville, NY, is depending on the newest technologies, latest materials and good project management to meet the construction deadline. In concert with NYCDOT, they are blending their disciplines to provide several important quality improvements.

Stainless Steel Rebar

Chris Sklavounakis, Director of Design Build and Emergency Contracts, for NYCDOT's Division of Bridges, for example, was convinced from the start that only solid stainless steel reinforcing bar could provide the long term durability and corrosion resistance needed for this bridge to provide safe service under an extremely heavy traffic load for 100 years or more. It will have to accommodate not only the current flow of 166,000 cars, trucks and buses daily, but also a significantly larger volume of traffic that will grow exponentially over the years.

The new bridge, like the one it replaces, will be exposed to the corrosive attack of a marine environment – the Atlantic Ocean a half mile away – and salt frequently spread on the roadway to melt snow and ice. Such attack could lead to expensive road repair and bridge deterioration. To sidetrack this potential problem, NYCDOT decided to use solid stainless steel reinforcement bar because of its inherent resistance to general corrosion.

No other rebar materials, clad or coated, were considered as options because they didn't offer the long life demonstrated by stainless steel. Sklavounakis figured that the lower life cycle costs for stainless steel rebar would more than justify the slightly higher initial cost of that material, compared with black carbon steel, which was used in the original bridge.

Subsequently, a decision was made to use UNS S31803 alloy, a duplex stainless steel known as Alloy 2205 by Carpenter Technology Corp., Reading, PA (NYSE:CRS), who was chosen to be the manufacturer. This alloy has excellent resistance to general rust corrosion. Key elements added to this steel to prevent corrosion are: chromium, molybdenum and nitrogen. Even pitting and crevice corrosion, which can occur in 18-8 type stainless, is unlikely in this alloy.

The specialty alloys producer has provided approximately 360,000 lbs. of No. 5 (5/8" or 16 mm dia.) and 40,000 lbs. of No. 7 (7/8" or 22 mm dia.) spiral ribbed Alloy 2205 rebar for use in the bridge superstructure. This is one of several projects in the New York City metropolitan area that have used solid stainless steel reinforcement bar from Carpenter.

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Based on contract allocations, the NYCDOT planner was correct in her value/cost assumption. The overall bridge project itself, including the bridge, modification in interchange configuration, reconstruction of Ocean Parkway, extensive landscaping, design and supervision is budgeted at $55 million. However, construction of the bridge alone will cost only $17.7 million.

Using Alloy 2205 stainless steel rebar instead of carbon steel rebar, she calculated, increases cost of the bridge by *approximately 1 percent*. In exchange for that small investment, NYCDOT is getting a bridge designed to *last more than twice the life of the 45-year-old bridge it is replacing*.

During that time, the owner will save the cost of a replacement bridge halfway through the century, at a cost likely to be twice that of the current $17.7 million outlay. In addition, NYCDOT will save countless millions of dollars in maintenance that will not be required, while freeing itself from the aggravation of repeated traffic tieups and community turmoil that generally accompany such maintenance.

"This is a major artery through Brooklyn carrying very heavy traffic," Sklavounakis said. "Our goal is to keep it moving. We cannot afford to replace the bridge every 30 or 40 years, nor did we want to spend city and federal funds on continual maintenance, causing disruption in the community every time work is required. It made good sense to spend a few extra dollars to put these problems behind us."

Precast Technology

Quality improvements and faster construction beneficial to the motoring public and the bottom line are conferred by Fort Miller, with its innovative precast concrete technology. Fort Miller, using its Inverset™ bridge system, makes precast, prestressed composite concrete and steel superstructure units away from the bridge site for easy installation when needed.

In this case, they and New York City are reinforcing concrete sections with stainless steel bar for the first time.

For this project, the company has produced 51 precast bridge units, each consisting of two steel beams and a concrete bridge deck. The bridge decks are cast using a unique upside down casting process that compresses the concrete and provides a highly durable, crack-resistant surface.

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All of the bridge units are precast and pre-assembled at Fort Miller's manufacturing plant in Schuylerville, about 200 miles north of the Belt Parkway bridge site in Brooklyn. Each Inverset unit is made of concrete produced in a state-of-the-art batch plant, then poured and cured under factory-controlled conditions. As the units are finished, they are set up in the same relative position to each other as they will be on the job site, for inspection by NYCDOT-Quality Assurance (QA). When the bridge site is ready, the precast bridge units can be transferred, like giant Legos, for installation as needed.

"This method of construction, compared with the conventional cast-in-place approach, will enable Granite Halmar to condense bridge construction time significantly," explained John Gonyea, Fort Miller Project Manager and Estimator. "Erecting the bridge components in a rural environment, " he noted, "remote from the busy job site, also minimizes the negative aspects of conventional construction."

The technique of setting precast units in place at the job site will allow the contractor to avoid traffic tieups on the Belt Parkway bridge and below on Ocean Parkway. Use of precast components produced under roof in a controlled environment, also will limit the contractor's exposure to bad weather, and its slowing effects on construction.

Also eliminated, or much reduced at the bridge site: the need to build forms for concrete pouring; water and wet burlap for curing concrete; concrete trucks; tractor trailers with reinforcement bar; excessive delivery equipment; machinery to finish the deck; conditions that can lead to accidents; and the dust, dirt and noise generated by the vehicles and equipment no longer needed.

Rebar Strength Requirements

Carpenter's 2205 stainless bar has been used extensively to reinforce the modular precast concrete bridge decks, bridge parapet, the fascia barrier and median barrier. A liquid corrosion inhibitor was added to the concrete mix because it was specified by the Precast Concrete Construction Manual (PCCM). However, Carpenter suggested that such use was unnecessary since the stainless rebar itself is corrosion resistant.

Since New York State Department of Transportation did not maintain a list of approved rolling mills for solid stainless steel reinforcement bar, and solid stainless steel reinforcement bar had not been used on NYCDOT bridge projects earlier, Muhammad Afzal, P.E., Director of NYCDOT-QA, required that stainless steel lots designated for use on the bridge be evaluated to

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ascertain the quality and characteristics of the material as claimed by its producer, Carpenter Technology. Thus, NYCDOT-QA used Pennoni Associates, King of Prussia, PA, to check every heat melted by Carpenter, observe the rolling of rebar, obtain and send rolled samples to the Materials Testing Lab, Inc., New Hyde Park, NY, in contract with NYCDOT-QA, to measure mechanical properties.

To establish mechanical property requirements, NYCDOT referred to ASTM standard A955M. Three yield strength grades are available: 300, 420 and 520 MPa. The typical yield strength grade used for black carbon steel is 420 MPa. However, prior history with Carpenter Alloy 2205 stainless rebar has shown that it is capable of meeting the 520 MPa yield strength minimum with superior ductility. This is 25% higher than the typical strength required.

When Materials Testing Lab evaluated the mechanical properties of two samples of No. 5 bar size, it determined a yield strength of 580 MPa, compared with the 520 MPa minimum requirement. Ultimate tensile strength was 790 MPa, compared with the minimum requirement of 725 MPa.

Even at these high strength levels, samples had elongation of 30%, compared with the required 9% minimum, giving the alloy excellent bending characteristics. The high strength and elongation of Carpenter 2205 alloy results in superior fatigue resistance, important in withstanding stress cycling of the bridge under heavy truck traffic. Deformation spacing met the ASTM requirement, as well.

Carpenter melted and rolled the 2205 stainless rebar in its Reading mill. Thermo-mechanical processing heavy cross sections with spiral configuration is not easily accomplished because of the alloy's high strength at elevated temperatures. The rolled product was shipped in 40-ft. lengths to Talley Metals, a subsidiary in Hartsville, SC, for acid cleaning and subsequent shipment to Denman & Davis, Clifton, NJ, metals distributor. That firm, in turn, sent the rebar to Fort Miller for storage, inspection by NYCDOT and fabrication.

Fort Miller cut the stainless rebar to various lengths from 5 to 40 feet, severely bent the ends and formed loops used to reinforce the edges of the decks and concrete closure pours. Fabricators were surprised at how easily they could bend the high strength stainless on standard rebar equipment.

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Bridge Site

Corrosion of reinforcing steel has always been a major concern for aging infrastructure. The Belt Parkway bridge being replaced was a 45-year-old two-span structure with steel stringers and cast-in-place, reinforced concrete deck that was rapidly deteriorating. Corrosion had taken its toll, exposing abutments badly and diminishing deck capacity. Road plates had been installed on the roadway, and timber shoring was supporting the abutments that had lost their capacity. It was a classic case of "band aid" repair and maintenance, with no alternative course of action available short of bridge replacement.

In addition to those challenging conditions, NYCDOT had to consider how it was going to demolish the old bridge and build the new one without disrupting the lives of thousands of neighbors who occupied/visited a large hospital and two schools fronting on the project limits. How, indeed, could the contractor manage, as he predicted, to keep the same six lanes of traffic moving through the construction area without any major delays? This was a major undertaking at a busy interchange involving two heavily traveled roadways carrying traffic in four directions.

The replacement bridge, to be installed quickly with modular pre-cast concrete units, will be longer than the old bridge. It will use three spans to better serve the traffic needs of the Ocean Parkway underneath, separating its mainline from its service roads and accommodating wide sidewalks and two malls. One of the malls will be landscaped and the other dedicated to pedestrians and bicycles.

The new bridge will have shoulders and will be widened from 36 meters (117 ft.) to 40.5 meters (133 ft.) In addition to carrying three lanes each way, the added width allows for an acceleration and deceleration lane at the ends of the bridge to ease vehicle access and departure. The extra width also allows for the introduction of shoulder lanes, a feature that is now missing from the Belt Parkway.

Units Delivered

Fort Miller has produced, for pre-assembly on the grounds of its manufacturing plant, a large volume of precast reinforced concrete components including the 51 bridge units, eight pier caps, 530 square meters of precast concrete T-Wall™ used to construct the abutments, 250 meters of bridge and approach barrier, and approximately 1600 meters of highway barrier. Delivery of various components to the bridge site started in April of this year.

The three precast concrete spans are each 40.5 meters (133 ft.) wide when assembled, generous enough to accommodate three lanes of traffic each way. Their lengths vary. Span 1 is 20 meters (65 ft.) long, Span 2 is 33 meters (107 ft.) long and Span 3 is 15 meters (49 ft.) long. Total deck surface is 2,715 sq. meters (29,000 sq. ft.).

Each of the three spans consists of 17 bridge units, with two Inverset beams and reinforced concrete deck, that vary in width between 2.38 and 2.5 meters. The 51 bridge units are easily linked together and taken apart for delivery to and installation at the bridge site.

According to plan, all six lanes of traffic are to be open during rush hours, with limited lane closures during off-peak hours for timely bridge work. To maintain uninterrupted traffic flow, Granite Halmar installed a temporary bridge on the south side of the existing bridge. The traffic riding the northern portion of the bridge (westbound traffic) was diverted on the southern portion of the bridge (eastbound traffic) and the traffic that used to ride the southern portion was shifted onto the temporary bridge. This allowed the contractor to demolish the northern half of the old bridge.

In the space once occupied by the demolished half, the contractor was ready to set in place precast bridge units. In a joint effort between Granite Halmar and Fort Miller, the entire bridge superstructure was erected at the fabrication plant on temporary cap beams, steel diaphragms were pre-drilled and all fit-up issues were resolved. This investment mitigated field uncertainties, further limited the amount of work required at the site and reduced the project’s impact on the community and traveling motorists.

With heavy mobile cranes and large trucks, the precast bridge units were transported from the precast plant in Easton and moved into position at the bridge for installation. The deck sections were quickly and efficiently linked with small closure pours of concrete in holes and open edges provided in the cast structures. Construction crews worked multiple, extended shifts (with heaviest duty at night) to place and bind the sections together.

The north side of the bridge was erected in May (as in one month)! That effort consisted of setting 27 sections – nine pieces wide x three spans long. This construction phase actually took only a "*couple of nights*" in each of two weeks, reported Atkins. The two-week time frame was needed to comply with New York City restrictions on oversized trucks and travel.

With the north side of the new bridge set in place, its increased width allows for both the westbound and eastbound traffic in a temporary lane configuration. Then, the temporary bridge and the old bridge on the south side will be demolished.

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In its place, the contractor in September will set the second half of the new bridge on the south side, again in a few nights in each of two weeks, also observing the same restrictions on heavy vehicular traffic. In this phase, 24 units – eight pieces wide x three spans long – will be installed. After the second construction phase is completed, the entire new bridge will be operating in its final design configuration.

Once the contractor starts installing the precast bridge units, the bridge units go up so fast that most observers don't realize what is happening. That's why Fort Miller calls its precast technique "invisible construction."

To build this bridge by conventional cast-in-place construction methods, in a similar phasing plan, Atkins estimated, would take a year rather than a few days. That, he added, would depend on the number of shifts per day and weekends worked – which are strategies that would adversely impact the community and violate NYCDOT's desire and strict direction to protect residents and the traveling public from undue inconvenience.

# # #

For more information about the bridge from NYCDOT, contact Chris Sklavounakis at: phone (212) 788-2078; fax (212) 788-1911; e-mail csklavounakis@DOT.NYC.gov

For more information about Fort Miller's precast construction, contact John Gonyea at: phone (518) 695-5000; fax (518) 695-4970; e-mail jgonyea@FMGroup.com

For more information about bridge construction, contact Paul Atkins at: phone (914) 668-9500 Ext. 134; fax (914) 668-9542; e-mail Paul.Atkins@gcinc.com

Carpenter Technology Corporation, based in Wyomissing, PA, USA, is a leading manufacturer and distributor of specialty alloys and various engineered products. Talley Metals, a Carpenter subsidiary based in Hartsville, SC, USA, sells selected alloys to distributors.

Editor's Note: Talley Metals branded its solid stainless steel rebar in 2006. Therefore, Alloy 2205 is being manufactured and sold by Talley as EnduraMet™ 2205 stainless.

Choosing Stainless Steel Rebar

by:
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Compared to carbon steel, stainless steel rebar is marginally heavier, stronger, has far superior corrosion resistance, is more ductile and can be nonmagnetic—good qualities to consider.

Use of high-strength, corrosion-resistant stainless steel rebar for concrete reinforcement in bridges, highways, buildings and other construction projects has been on the rise—especially when the life cycle costs of this material upgrade are appropriately weighed against carbon steel. The trend to stainless has been particularly evident in coastal areas of the USA, and in Canada and Europe.

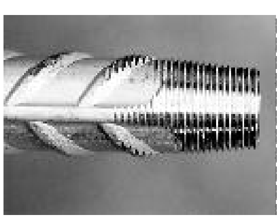
Increasingly, the higher up-front costs of solid, spiral ribbed stainless steel rebar can be justified when compared with the initial costs, lifetime maintenance costs, replacement costs and operating costs incurred when using carbon steel rebar, with and without cladding or coating.

In practice, stainless steel rebar has been used in many concrete structures to provide high strength and long-term resistance to the corrosive attack of chlorides from road salt and harsh marine environments which penetrate the concrete in which the rebar is buried. Carbon steel will corrode leading to concrete spalling.

The most dramatic example of the longevity difference between carbon and stainless rebar can be found in Yucatan, Mexico, where a marine pier constructed in 1937 with stainless rebar is still in use while the pier constructed in 1960 with carbon steel is in ruins.

Applications for corrosion-resistant stainless rebar include a host of marine structures such as bridge decks, sidewalks, ramps, parapets, pilings, barriers, retaining walls, anchoring systems, parking garages, sea walls, columns, piers, jetties and moorings. Stainless rebar can be considered also for the infrastructure of chemical and other process plants where corrosion resistance is important.

Stainless steel rebar, offering a good combination of high strength, toughness, ductility and fatigue resistance, along with corrosion resistance, has been used for construction of bridges and other structures in seismic areas. Of paramount concern here is the need for high strength and ductility to preserve the structural integrity of any bridge subject to a seismic disturbance, and the safety of motorists using it.



Threaded stainless steel rebar.

There are also an increasing number of rebar applications, requiring controlled magnetic permeability, where carbon steel cannot be considered an option. Nonmagnetic stainless steel rebar has been used successfully in electric motor foundations and in buildings that house MRI and similar equipment.

In addition, the same nonmagnetic stainless alloys have been used in constructing "deperming" piers, where the proper function of instrumentation is restored in docked ships before they return to sea.

Appropriate Stainless Alloys

Although *ASTM A 276* lists a good number of stainless alloys that are suitable for use in concrete reinforcement, any one of four major stainless steels can be considered for most applications. These are 2205 stainless (S31803), stainless type 316LN (S31653), 18Cr-3Ni-12Mn stainless (S24000) and stainless type 304LN (S30453).

For rebar applications, the process should start with the designed mechanical property requirements. *ASTM A955*, covering deformed and plain stainless steel bars for concrete reinforcement, lists these requirements. This standard allows stainless steel rebar to be produced at three strength levels.

However, Carpenter can achieve a yield strength of 75 ksi (518 MPa) or higher for all four alloys to be considered, and a tensile strength of 100 ksi minimum (690 MPa). These values represent the highest of the three strength levels listed by *ASTM A955*. The highest strength level can be reached in all standard bar diameters from No. 3 to No. 14 or 0.375" to 1.75" (10 to 45 mm) diameter—metric sizes are available as well. Strength levels, in fact, can be tailored to bar size by modifying the hot rolling production parameters.

All four stainless steels offer exceptional ductility, which allows the rebar to be easily formed and fabricated. Their elongation properties are in the range of 20% to 30%, which is greater than the 7% to 12% minimum elongation in *ASTM A955* for the same alloys at the 75 ksi (518 MPa) yield strength level. Elongation is a key property of fabricators who perform numerous bending operations. In addition, all four alloys have good toughness and fatigue resistance.

This unique combination of mechanical properties makes all four stainless steels candidates for construction projects in seismic areas. Their high strength levels allow designers to use less material and conserve weight. Their good ductility permits structures to flex without breaking during any seismic disturbance.

Selection of the best candidate stainless steel for a rebar application may depend on the amount of corrosion resistance required, particularly in view of the similarities in the alloys' key mechanical properties. Of the four rebar grades discussed, 2205 stainless offers the best overall corrosion resistance.

Three of the four alloys discussed may be considered for those rebar applications where controlled magnetic permeability is most important—type 316LN alloy, 18Cr-3Ni-12Mn stainless and type 304LN.

Applications

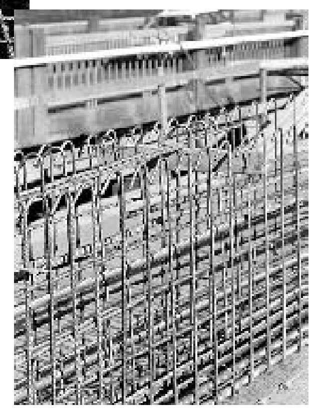
Over 200 tons of stainless steel rebar was recently supplied to **The Fort Miller Co.**, Schyulerville, NY, USA. Carpenter 2205 duplex alloy rebar was used to produce precast concrete modules for a new **NYSDOT (New York Department of Transportation)**-designed highway bridge (the **NYC DOT** was equally involved). The bridge will be on the Belt Parkway, over the Ocean Parkway, in Brooklyn, NY, USA. Fort Miller precast the modules in a climate-controlled facility and then completely assembled the structure on its property. After inspection, the bridge will be disassembled, moved to the site and reassembled quickly and efficiently. The modular approach and the use of stainless steel rebar helped meet the two main objectives specified by NYSDOT:

- Erect the bridge in a busy urban area with minimum disruption to traffic and the surrounding neighborhoods;
- Erect a bridge that will last a lifetime with minimal maintenance.

This is the first major use of stainless rebar in a precast application in the USA. Other conventional onsite USA bridge projects utilizing stainless rebar include the Haynes Inlet Slough Bridge in Oregon (400 tons of stainless rebar expected to provide maintenance-free service for 120 years), Driscoll Bridge in New Jersey (using 1300 tons stainless rebar) and the Woodrow Wilson Bridge which spans Maryland and Virginia (about 1000 tons). These projects should provide the catalyst for DOT engineers to specify stainless rebar.

Typically the use of stainless vs. black carbon rebar adds only incremental cost for greater benefits. The bridge in Brooklyn only had an increase in the cost of the bridge of about 1% by using stainless rebar, a small

Stainless steel rebar on the Haynes Inlet Slough Bridge deck.



Vertical arrangement of bent stainless rebar; Haynes Inlet Slough Bridge.

price to pay for the long-life benefit you get. With stainless rebar, the high cost of corrosion inhibitors can be eliminated.

Asia is a fairly new market for stainless rebar as well. Three big projects in Asia are coming up: West Corridor which will connect Hong Kong to mainland China and use 1300 tons of stainless rebar, Stonecutters Bridge using 3000 tons of stainless rebar and probably that much in carbon rebar and a bridge to Disney World being built on Lantau Island in Hong Kong. Total Asian demand in the next two to three years is about 7000 tons. Canada, Europe and the Middle East fabricators have been using stainless rebar for a while.

Conclusion

Everyone knows there is a need to upgrade the use of black carbon rebar when you expect corrosion problems. Different coatings and claddings have been tried, but they have not met expectation, so now bridge designers are using solid stainless rebar because they know it will work. We're helping bridge designers and DOTs understand the value of using solid stainless bar, and we have brought expanded sizes and lengths to the market.

For more information on stainless steel rebar, contact the author or **Circle 205.** WFTI

Company Profile...Carpenter Technology Corporation *is a leading manufacturer and distributor of specialty alloys including stainless steel and titanium, and various engineered products made from metallic and ceramic materials.*

NEWS

CARPENTER

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**STAINLESS STEEL REBAR FOR CONCRETE REINFORCEMENT
WHERE CORROSION RESISTANCE, HIGH STRENGTH ARE NEEDED**

WYOMISSING, PA, USA (June 21, 2002) – Carpenter Technology Corporation (NYSE:CRS), through its Talley Metals Technology Inc., subsidiary, is now producing several grades of high strength stainless steel rebar that have been used for concrete reinforcement in a wide range of construction projects where structures require long term resistance to the attack of chlorides from the concrete, road salt and harsh marine environments.

The spiral ribbed stainless rebar has been used to resist corrosion in a variety of marine applications such as bridge decks, sidewalks, parapets, pilings, barriers, retaining walls, anchoring systems, parking garages, sea walls, piers, jetties and moorings. It might also be considered for chemical plant infrastructure.

Non-magnetic stainless rebar in the new product line can be considered for use in electric motor foundations, and in the construction of buildings housing MRI equipment. In addition, the same non-magnetic alloys are available as candidates for use in constructing “deperming” piers, where the proper function of instrumentation is restored in docked vessels before they return to sea.

The new line of stainless rebar has been offered as an alternative to materials such as carbon steel and products that are either coated or clad but, lacking adequate corrosion resistance in marine environments, have incurred excessive repair and replacement costs. The higher cost of stainless steel rebar, the company says, can be justified by its long design life and minimum maintenance requirements.

Talley is currently offering its stainless rebar in several grades, all of them providing an excellent combination of strength, toughness, ductility, formability, fabricability, fatigue resistance and corrosion resistance. In the hot rolled condition, yield strength of 75 ksi (518 MPa) or higher can be achieved for all four alloys in bar diameters up to 1.375 in. (34.9 mm or No. 11).

At this high yield strength level, all four alloys can be considered for construction in areas of active seismicity. In addition, they provide good ductility – in the range of 20% to 30% elongation – allowing the rebar to be effectively fabricated.

2205 stainless (S31803) is a duplex stainless steel with a microstructure consisting of austenite and ferrite phases. This duplex microstructure, along with the chemical composition, give the alloy an excellent combination of strength and corrosion resistance. It offers the best corrosion resistance of the four rebar grades.

Compared with conventional austenitic stainless steels like Type 304 and 316, 2205 stainless has superior chloride pitting and crevice corrosion resistance, due to higher chromium, molybdenum and nitrogen content, and superior resistance to chloride stress corrosion cracking because of its duplex microstructure. In the annealed and hot rolled conditions, 2205 alloy is ferromagnetic.

Stainless Type 316LN (S31653), a nitrogen-strengthened version of stainless Type 316L, has significantly higher yield and tensile strength than Type 316L without adversely affecting ductility, corrosion resistance or non-magnetic properties.

The low magnetic permeability of Carpenter Stainless Type 316LN is a key property in rebar applications that have been in close proximity to sensitive electronic devices or magnetic resonance medical equipment. Its high strength is an added economic advantage. The alloy also can be considered for all of the applications mentioned previously that require good corrosion resistance.

In general, the corrosion resistance of stainless Type 316LN is similar to that of stainless Type 316L.The higher nitrogen content enhances its resistance to chloride pitting and crevice corrosion. Due to its low carbon content, stainless Type 316LN has good resistance to intergranular corrosion in the as-welded condition.

18Cr-3Ni-12Mn stainless (S24000) is a high-manganese, nitrogen-strengthened austenitic stainless steel that provides substantially higher yield and tensile strengths than stainless Type 304, and general-corrosion resistance between that of stainless Types 430 and 304.

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Like the stainless Type 316LN alloy, this stainless steel is also nonmagnetic in the annealed and hot-rolled conditions. It, too, can be considered for use near sensitive electronic devices and medical resonance imaging equipment.

18Cr-3Ni-12Mn is a candidate alloy for rebar applications where corrosion resistance approaching stainless Type 304 is adequate, but where the strength or magnetic permeability of stainless Type 304 is unsuitable. The 18Cr-3Ni-12Mn alloy has good resistance to atmospheric corrosion.

Stainless Type 304LN (S30453) is a nitrogen-strengthened version of stainless Type 304L available in the hot rolled condition. This grade has a much higher yield and tensile strength than Type 304L, without any loss in ductility, corrosion resistance or non-magnetic properties. It has corrosion resistance similar to that of the 18Cr-3Ni-12Mn alloy.

Like stainless Type 316LN and 18Cr-3Ni-12Mn alloys, stainless Type 304LN is also nonmagnetic in the annealed and hot rolled conditions. It can be considered, therefore, for use near sensitive electronic devices and medical resonance imaging equipment.

All four stainless steels for rebar are available in lengths of up to 40 ft., in diameters from ½-in. (12.7mm or No. 4) to1-3/8-in. (35 mm or No. 11) with short lead time.

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Carpenter Technology Corporation, based in Wyomissing, PA, USA, is a leading manufacturer and distributor of specialty alloys and various engineered products.

Talley Metals Technology, Inc., a Carpenter subsidiary based in Hartsville, SC, USA, sells selected alloys to distributors.

Editor's Note: Talley Metals branded its solid stainless steel rebar in 2006. Stainless steel rebar is being manufactured and sold as:

EnduraMet™ 32 stainless (formerly 18Cr-2Ni-12Mn stainless)
EnduraMet 2205 stainless
EnduraMet 316LN stainless
EnduraMet 33 stainless (formerly 18Cr-3Ni-12Mn stainless)
EnduraMet 304LN stainless

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NEWS

CARPENTER

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NEW BRIDGE USING STAINLESS STEEL REBAR TO LAST 120 YEARS IN CORROSIVE MARINE AND EARTHQUAKE ENVIRONMENT

NORTH BEND, OR, USA (May 29, 2002) – The Oregon Department of Transportation (ODOT), using highly alloyed stainless steel reinforcing bar in its concrete structures, is building a bridge here that is expected to provide maintenance-free service for an amazing 120 years, nearly 2.5 times the service life of the bridge it is replacing.

Frank Nelson, bridge preservation managing engineer for ODOT, figures the taxpayers are getting a huge bargain. When finished by the end of 2003, the bridge will cost approximately $12.5 million. The stainless steel rebar, utilized in the most critical structural elements, accounts for only 13 percent of the total bridge cost.

For that small increase, he observed, ODOT will save the cost of bridge replacement in 50 years. That is a sum likely to be $25 million dollars, or at least twice the cost of bridge construction today. As an alternative, the money saved could be used to build another bridge. Meanwhile, the new structure will require little more than routine examination.

The new bridge, carrying U.S. 101 over the Haynes Inlet Slough near the coastal town of Coos Bay, is using what is believed to be more stainless steel rebar than any bridge in North America - 362,878 kg or nearly 400 tons. Yet this is not an ordinary stainless steel because it had to meet some very challenging requirements for corrosion resistance, strength and site seismicity.

Along the Oregon coast, the marine environment is very hostile to bridges. Salt-laden air and fog from the Pacific Ocean condense under the deck and T-beams of this bridge. Wind blows the chloride-containing moisture underneath the structures, initiating corrosion. Rain washes the chlorides off the road surface, but flushes away nothing below.

ODOT considered stainless-clad bar and epoxy coating of carbon steel rebar, but decided neither possessed sufficient durability nor long-term resistance to chloride-induced corrosion. The concrete in which the rebar is embedded will eventually become contaminated with corrosive chlorides.

Haynes Inlet Slough bridge, Oregon

Extraordinary strength was required of the stainless to facilitate design of the new bridge and to deal with the potentially devastating seismic activity in this area. ODOT specified that the stainless alloy used had to have a minimum yield strength of 75 ksi (520 MPa). That strength level is new to bridge building and substantially higher than the 60 ksi (420 MPa) minimum yield strength required of the Type 316LN stainless used for rebar in ODOT's Brush Creek and Smith River bridges replaced a few years ago. In addition, the alloy also had to provide high ductility (25 percent elongation) so it could be effectively fabricated.

In view of the area's geological history, Bridge Designer James Bollman had a study done to determine design seismicity and collapse criteria. Ground surface accelerations were intended to forecast a 1000-year probability seismic event. Ground surface acceleration was calibrated at 1.05 g maximum, and peak bedrock acceleration at 0.54 g. The bridge, consequently, has been designed to remain serviceable with only a 10 percent probability over its lifetime of the site seismicity exceeding the design seismicity.

It was clear that ODOT, its goal set on extending bridge life, wanted this to be its strongest bridge yet. With a higher strength stainless alloy than any it had used to date, Bollman also expected to enjoy an economic advantage of less stainless rebar weight than would have been required using 60 ksi alloy.

Stainless Alloy Choice

Farwest Steel Corp., Eugene, Ore., a steel distributor and rebar manufacturer, suggested trying Alloy 2205, a duplex stainless steel provided by Talley Metals Technology, Inc., Hartsville, S.C., a subsidiary of specialty materials expert Carpenter Technology Corp. ODOT was counting on Farwest Steel to fabricate the rebar it needed from rolled mill stock.

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Talley's 2205 stainless has a duplex microstructure, mixing austenite and ferrite phases, that gives the alloy the required 75 ksi yield strength. This is 25% more yield strength (per ASTM-A-955) than that of austenitic Types 316LN and 304 stainless steels (60 ksi) which are more common candidates for bridge rebar.

With improvements in hot rolling procedures, in fact, the company has been able to produce 2205 stainless steel bar in a yield strength range of 85 to 95 ksi. At the same time, while increasing strength, it has managed to exceed the 25 percent elongation requirement that reflects ductility. That means its 2205 alloy rebar has superior fatigue resistance. Thus the alloy can better withstand movement of the bridge and stress cycling under heavy truck traffic.

Talley delivers its spiral-ribbed rebar to Farwest Steel in the as-rolled condition, pickled and acid cleaned with surface free of oxides. The company, the first alloy producer to hot roll this high strength product - far from a routine procedure, has provided lengths of up to 30 feet in various sizes from 0.375" to 1.375" round (Nos. 3 through 11).

With a careful balance of chromium, molybdenum and nitrogen content, 2205 stainless steel offers superior resistance to chloride pitting, crevice corrosion, stress corrosion cracking and general corrosion in many environments. Its resistance to corrosion is substantially better than that of the Type 316LN stainless ODOT used in previous bridge reconstruction.

Nominal analysis of 2205 alloy is: carbon 0.030 percent max, manganese 2.0 percent max, phosphorus 0.030 percent max, sulfur 0.020 percent max, silicon 1.0 percent max, chromium 22.0 percent, nickel 5.5 percent, molybdenum 3.0 percent, nitrogen 0.14 percent, balance iron.

ODOT fully expects Talley's 2205 stainless steel rebar to solve the corrosion problems it has experienced in vulnerable concrete coastal bridges. On a regular basis, inspectors used to drill into the concrete for core samples to measure chloride infiltration. They generally found that chloride ions had penetrated the hardened concrete of the most exposed structures, causing serious cracking, delamination and spalling.

Chloride intrusion, accelerated by the tensile cracking of the concrete caused by the relentless load of heavy moving traffic, then caused cracking between concrete and bars along the length of the original carbon steel rebar. With time and more traffic, the cracking caused rust, which occupies a volume greater than that of the original metal. This reaction led to spalling and, with pieces falling away, a further loss of bond between concrete and the steel. As structural members are weakened by corrosion, the increased stress on remaining members could lead to structural

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failure. With carbon steel rebar, structural failure has occurred in as short a time as 17 years. In contrast, the 2205 alloy is expected to last well over one hundred years.

Bridge Design

Along with the duplex stainless alloy rebar, ODOT is using a much larger volume of 614,000 kg of grade 60 uncoated carbon steel rebar in the new bridge for substructure elements where corrosion is less of a problem. The two different steels are, for the most part, being used independently in different structural elements. Where they are used together, the stainless rebar is covered with a PE (polyethylene) sleeve at all points where the dissimilar metals intersect to prevent the possibility of galvanic corrosion.

The new bridge, 773 feet long and 85 feet wide, with rising, curving approaches, is a series of three spans of two-hinge cast-in-place concrete deck arches. An estimated 14,000 vehicles a day use the bridge, which carries the busy Oregon Coast Highway over an estaurine inlet. Hamilton Construction Co., Eugene, is the general contractor in charge of construction.

Hamilton left the older, heavily timbered bridge in place to carry traffic while the east half of the new bridge was completed in Phase 1 of the project. Now, in Phase 2, the finished east half is carrying traffic, while the old bridge is being removed and the west half is built to join the east half. While the old bridge had two lanes, the replacement bridge will have five.

To increase resistance to corrosive attack on the new bridge, Bollman had all bridge elements above the footings cast with microsilica concrete. This type of concrete is less permeable to corrosive chloride ions than conventional concrete. He specified also that Talley's 2205 stainless alloy rebar be used to reinforce the deck, deck support T-beams and the rail curb on the edges of the bridge.

The deck and T-beams are typically the first to suffer the effects of corrosion because they are thinner than the main support members, and subjected to bending forces and dynamic loads from heavy trucks that cause significant stress cycling in both the rebar and concrete. Substructure elements, in compression under service load, do not experience stress cycling under service load into the tensile range. They are, therefore, less susceptible to damage from chloride intrusion.

The arch design harmonizes with Oregon's other coastal bridges and, in particular, the beautiful nearby Conde McCullough Memorial Bridge. The two-hinge arch design also allows for more slender arch ribs, which enhance the bridge appearance and also help meet the challenging seismic conditions. Without vertical bending, a more slender arch is possible at its support. This

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allows for smaller and less stiff supporting pedestals and footing, thus less cost for those foundation members.

All concrete members excepting the arch ends are monolithic, with reinforcement running completely through. This feature enhances the seismic energy absorptive capacity, which is a key element of bridge seismic resistance.

At the end of the ribs, hinges that have been made of 2205 stainless steel plate are submerged in brackish water of the estuary at high tide. These hinges preclude in-plane bending of the arch ribs at their supports for either live or dead load. Pins used with the hinges are made of a non-galling, corrosion resistant stainless steel.

Rebar Path

After Farwest Steel receives hot rolled 2205 alloy rebar from Talley, it cuts pieces to specific lengths, bends some (because of the alloy's good ductility) and adds LENTON®* taper threads to the ends of the No. 10 bars. The fabricator requires Talley to comply with a straightness tolerance of no more than 1-inch deviation over a 5-foot length. Straightness is important because the company cuts a quantity of bar at a time in a tray, butting all the pieces against the same reference plate. The cutoff must produce bars of exactly the same length. Then the fabricated product is wrapped in plastic and shipped to Triad Steel Inc., subcontracting ironworker, at the bridge site.

Triad, based in Springfield, Ore., then positions the stainless rebar in forms in accordance with CAD placing drawings provided by Farwest Steel and ODOT. Responsible to Hamilton Construction, Triad then lap splices the 2205 alloy rebar with stainless tie wire, or joins lengths with LENTON mechanical couplers that have been made by ERICO®*, Inc., Solon, OH, from the same Talley alloy.

When 2205 duplex stainless rebar is joined by good lapping technique, the lapped joint has developed a yield strength of 75 ksi. However, the ERICO LENTON taper threaded 2205 alloy coupler, torqued onto the 2205 alloy rebar threaded by Farwest Steel, has developed an ultimate tensile strength of 100 ksi. In tests, strength as high as 130 UTS has been reached for LENTON. Under new construction codes, there is greater reliance on mechanically coupled rebar to transfer loads and stresses than there is on concrete, which can be adversely affected by salt, chlorides and other environmental conditions.

*registered trademark of ERICO, Inc., Solon, OH

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The LENTON mechanically coupled 2205 stainless rebar has been used extensively in the bottom of the T-beam which supports the bridge deck above the arch. It was chosen by ODOT for this application because its greater strength and corrosion resistance were needed here, and also because the coupled rebar, compared with lapped rebar, occupied less of the limited space available.

Slippage must be held to a minimum at the joint between the rebar and coupler because of the perpetual seismic threat and the tensile stress cycling from truck traffic. With the ERICO LENTON couplers, slipping motion has been held to 0.003-in. maximum at half the specified yield strength. This is significantly better than the maximum 0.010-in. slip allowed by the ODOT specification. No other coupler system tested was found capable of meeting the tight slip specifications for this job. When the bridge is fully loaded, the general operating stresses are about ½ the yield strength.

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For additional information about the Haynes Inlet Slough Bridge contact Jim Bollman at ODOT at phone (503) 986-3341, fax (503) 986-3407 or e-mail <James.N.Bollman@odot.state.or.US>.

For additional information about ERICO LENTON couplers and other products, contact ERICO customer support at 1-900-248-2677 or visit the company website at www.erico.com

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Carpenter Technology Corporation, based in Wyomissing, Pa., USA, is a leading manufacturer and distributor of specialty alloys and various engineered products. Talley Metals Technology, Inc., a Carpenter subsidiary based in Hartsville, S.C., USA, sells selected alloys to distributors. More information about Carpenter and Talley is available at www.cartech.com.

Editor's Note: Talley Metals branded its solid stainless steel rebar in 2006. Therefore, 2205 stainless is being manufactured and sold as EnduraMet™ 2205 stainless.

Stainless steel hinge pins anchor bridge retrofit

John A. Blatnik Bridge total reconstruction in Duluth will widen I–535 using pier caps, new steel and wear-resistant stainless steel pins

edited by Tom Kuennen

The Minnesota Department of Transportation, focusing on motorist safety and longer bridge life, has specified stainless steel for the link hinge pins used in reconditioning the 7,975-ft-long Blatnik Bridge in Duluth.

The Blatnik Bridge, conveying I–535, serves as the main connector between Duluth, Minn., and Superior, Wis. Other recent Duluth work includes I–36 tunnels at the lakefront (see *Tunnels Make Duluth's I–35 Project Stand Out*, November 1989, p 43), and reconstruction of the Maj. Richard I. Bong bridge (see *$70 Million Bong Bridge Links Wisconsin, Minnesota*, July 1985, p 71).

Its central span, 600 ft long, with 270 ft spans on either approach, are of side steel truss design. The approach spans on both sides are welded plate girder spans (for more on this major project, see related sidebar).

New steel girders are erected as part of Minnesota DOT Blatnik Bridge widening project

The switch from low alloy steel pins to stainless steel pins is a first for the department. But it was a logical choice, as these fracture-critical members must possess high-strength, corrosion resistance and two other characteristics just as important: galling resistance, and the right coefficient of expansion. Two pins at the top and bottom of two opposing hanger plates pass through girder webs and act as a hinge that moves with expansion and contraction of the bridge, absorbing the moving load of overhead traffic.

The high volume of trucks, buses and other motor vehicles using the bridge makes high strength a paramount requirement for the long term. Generous use of road salt, and a rugged northern environment, call for the corrosion resistance of stainless steel. Perhaps more important is movement of the massive steel and concrete structure with changes in temperature. Pins in the hanger assembly are designed to rotate as the bridge sections move. For this reason, the department's structural metals engineer wanted a stainless grade that would not gall or wear when rubbing against other metal surfaces under heavy load.

Lewis Engineering Co., Chaska, Minn., was awarded the contract to make the hinge pins from ASTM 276 Type S20161, Type S21800 or the equivalent. The steel fabricator researched its options and determined that a stainless alloy developed by Carpenter Technology Corp., Reading, Pa., would work in this application.

Gall-Tough stainless is a high-silicon, high-manganese, nitrogen-strengthened, austenitic stainless alloy which possesses superior self-mated galling and metal-to-metal wear resistance. This alloy displays higher strength and high-temperature oxidation resistance than Type 304 stainless with comparable corrosion resistance, depending upon the environment. Lewis Engineering fabricated the hinge pins from stainless bar stock, in diameters of 5, 7, 8 and 9 in., and in lengths, proportionate to diameter, of 12 to 18 in.

Both ends of the pins were turned down, threaded and a hole drilled through each end for a cotter pin. The mating hanger plates are made from ASTM A-588 steel $1\frac{1}{2}$ in. thick. The plates vary in size from 12 to 16 in. wide by 35 to 68 in. long. Threaded, recessed nuts for each end of the hinge pin are made of the same material. Holes for the hinge pins are bored through each hanger plate, finished

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Information for this article contributed by Carpenter Technology Corp., Reading, Pa.

and coated with a rust inhibitor.

To help minimize pin wear, a ¼-in.-thick bushing of a low-friction fiber is press-fit into each of the hanger plate holes. The inside diameter of the bushing provides a clearance of 0.005-in. minimum and 0.010-in. maximum over the finished diameter of the hinge pin. Length of the bushing is the same as the hanger plate thickness.

On the bridge, the stainless alloy pins are pushed through the bushing in one hanger plate, through the steel web of the girder suspender, then through the bushing in the hanger plate on the opposite side. Each hanger plate assembly is held in place by recessed steel nuts and ½-in. cotter pins. High-density polyethylene washers are used as spacers between the hanger plates and pin plates. The hanger plate assemblies were installed on the bridge by ironworkers using hydraulic rams.□

CARPENTER TECHNOLOGY CORPORATION

CARPENTER STEEL DIVISION

Three-year job rebuilds Duluth bridge

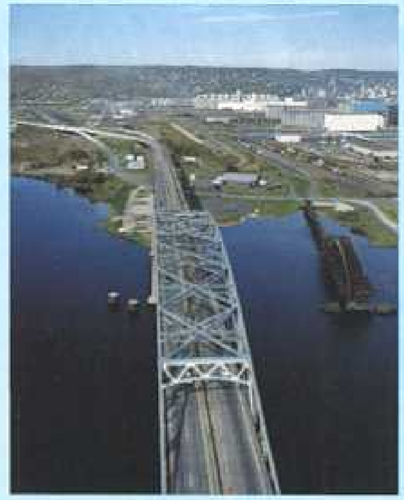
A three-year, $32.5 million reconstruction project will add new lanes and deck to the I-535 bridge crossing St. Louis Bay—the westernmost tip of Lake Superior—between Minnesota and Wisconsin at Duluth.

When major work is complete in 1994, each side of the John A. Blatnik Bridge will have been widened from an existing width of 27 ft 9 in., to 35 ft.

Phase 1 commenced in May 1992. Work involving the stainless steel pins took place during this phase. Phase 1 cost was $10.083 million.

Phase 2 began Sept. 7, 1993, and includes removal and replacement of the entire bridge deck, widening the structure to provide 8-ft wide outside shoulders, and all other major construction to prepare the bridge for traffic. The contract is for $19.767 million. **Johnson Brothers Corp.**, of Litchfield, Minn., is the prime contractor on Phases 1 and 2.

Phase 3 will consist of major painting of the structure, under traffic. The estimated $2.7 million job will be let in late 1994, with work to begin spring 1995.□



Blatnik replaced "Interstate Bridge" (old partial bridge to right of Blatnik). Remaining portion of Interstate Bridge is now a public fishing pier with boat launch.

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Improving Tomorrow's Infrastructure:

EXTENDING THE LIFE OF CONCRETE STRUCTURES WITH SOLID STAINLESS STEEL REINFORCING BAR

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In the wake of the I-35W Bridge collapse in Minneapolis, this paper is intended to heighten the awareness of the use of solid stainless steel reinforcing bar as a high-strength, corrosion-resistant alternative rebar product. It is not meant to imply that the use of solid stainless steel rebar would have prevented this catastrophe. However, in light of the need to rebuild America's infrastructure, attention should be focused on the FHWA slogan of "Bridges for Life." Stainless steel reinforcing bar has clearly demonstrated its 100+ year life expectancy.

Abstract

Stainless steel reinforcing has been used in numerous structures throughout North America, including the Progreso Port Authority Bridge, Yucatan, Mexico, in 1937; the Haynes Inlet Slough Bridge, North Bend, OR, USA, in 2002; the Belt Parkway Bridge over the Ocean Parkway, Brooklyn, NY, USA, in 2004; and Woodrow Wilson Memorial Bridge on the Capitol Beltway, Washington, DC, USA in 2006.

Recent advances in concrete technology have provided structural designers with materials which can easily last more than 100 years, and the life of many concrete structures today is limited by the reinforcing. Improvements in the life of the reinforcing can translate directly into extended life of the structure.

Current projections by several transportation agencies show that the use of solid stainless steel reinforcing bar in bridge decks will more than double the life of the bridge deck. While solid stainless steel reinforcing bar can increase the cost of the bridge deck by as much as 12% (compared to carbon steel reinforcing), the economic value of the longer life outweighs the initial higher cost. In most cases, the additional cost of solid stainless steel reinforcing bar represents less than 1.5% of the total cost of the structure.

Most concrete structures are designed with minimum concrete cover over the reinforcing bar, which is required to protect the reinforcing bar from corrosion. Where the reinforcing bar is completely resistant to corrosion, the cover can be reduced, saving costs of concrete and reducing the total weight of the structure. In some structures, design savings made possible by the use of solid stainless steel reinforcing bar will offset as much as 100% of the initial cost increase from using the stainless reinforcing.

Introduction

Corrosion of carbon steel reinforcing bar has been a serious issue for highway agencies around the world for many years. In the United States, these problems appeared in southern coastal states as long as 75 years ago, and appeared in many northern states after the use of deicing salts became common about 50 years ago. It would have been impossible in those early years of bridge design and construction for bridge and civil engineers to have foreseen the number of vehicles, and the huge loads that are being transported on these bridges today. In addition to the load concerns, deterioration due to the chloride salt content, either from the deicing salts employed or the salt spray in coastal regions, has severely impacted our bridge and roadway infrastructure. For the last 35 or 40 years, rebar corrosion has been one of the most important issues facing bridge engineers. Upon entering the 21st century, engineers are now being confronted with an enormous number of deteriorating bridges, and new solutions are being evaluated daily to address these rising concerns.

The Federal Highway Administration (FHWA) along with many of the various state Departments of Transportation (DOTs) began experimenting with methods to extend the life of concrete carbon steel reinforcing bar around 1970 as a result of these corrosion issues. The FHWA has also been tasked with the problem of seismic retrofit, due in part to the seismic activity that can occur in various parts of the United States. Therefore, high strength and excellent ductility are paramount in preserving structural integrity, in addition to corrosion resistance. Other FHWA projects include innovative bridge research and construction and value pricing projects based on full life cycle projections. Any or all the above mentioned projects may require a re-evaluation of the types of reinforcing materials currently being used.

MATERIALS EMPLOYED FOR REDUCING REINFORCING BAR CORROSION

Epoxy Coated Rebar

One of the first methods developed is still the most common: coating carbon steel with an epoxy coating. The epoxy coating is intended to protect the carbon steel from moisture and from salts, and to electrically isolate a rebar mat from other nearby mats that may be at different potentials.

Early bridge decks constructed with epoxy-coated reinforcement bar (ECR) did not exhibit the desired long life. Analysis of early failures showed that poor adherence, or the poor quality of the epoxy coating, allowed corrosive salts to penetrate. The concrete mixtures of that time had fairly high permeability, and the epoxy coatings provided only 5 to 10 years of additional life.

Subsequent testing showed that a principal cause of corrosion is the different potentials between the top and bottom mats in the deck. Many states began to use ECR in both the top and bottom mats for this reason (McDonald, et.al., 1998, and Samples, et.al., 1999).

However, the presence of uncoated composite shear studs in many bridge decks will provide an anode to initiate corrosion at defects in the top ECR mat. For this reason, the benefits of ECR bottom mats are limited.

The Concrete Reinforcing Steel Institute established a producer certification program for ECR, and the life of bridge decks using ECR is now in the range of 35 to 50 years in northern states where deicing salts are used (Humphreys, 2004).

The principal advantage of ECR is to provide longer life than that of uncoated carbon steel. Disadvantages include poorer bond with cement paste, fragility of the coating, adherence of the coating, and the limited life of the coating. While CRSI's certification program has substantially improved the initial quality of epoxy coatings, some studies have shown that damage to coatings during handling and concrete placement can be ten times the defects from the coating process itself (Samples, et.al., 1999).

High Performance Concrete (HPC)

Many agencies around the world have developed varieties of "high performance concrete" (HPC) in the last 15 years. Most of these mixes use substantially lower amounts of Portland cement than previous mixes, while adding fly ash, ground granulated blast furnace slag, and/or silica fume in various proportions. These mixes show a reduced heat of hydration and a slower strength gain than many of the older mixes. They generally tend to have less shrinkage, less microcracking, and a much lower permeability than the more "conventional" mixes.

Many tests have shown that corrosion rates in bridge decks are related to the amount of cracking (Smith, et.al., 1996, & Fanous, et.al., 2000). HPC bridge decks are more durable than those constructed with older mixes, and many agencies believe they can consistently achieve 50 years of life. Disadvantages are the slower curing times and, in general, the higher initial costs.

Galvanized Rebar

Many agencies began using galvanized carbon steel reinforcing bar more than 30 years ago. The galvanizing on carbon steel rebar has two functions: it protects the steel from corrosive chemicals, and it provides a sacrificial anode so that the steel itself will not corrode until the zinc coating is exhausted. Some agencies have had good results with galvanized reinforcing bar, but the overall record of galvanized reinforcing bar is similar to ECR (Burke, 1994, & McDonald, et.al. 1998).

An HPC deck with galvanized reinforcing bar is generally estimated to have a life of 35 to 50 years. The advantages of galvanizing include a better bond to the cement (compared to ECR), and a less fragile coating. Disadvantages include more price volatility, limited life of the coating, and the fact that galvanized rebar cannot be used in a placement with uncoated steel (because the coating will sacrifice itself to protect the uncoated steel nearby).

"Zn-ECR" Coatings

A U.S. producer has recently introduced reinforcing bar that is spray-coated with molten zinc and then epoxy-coated. Although it would appear that this product would have significantly longer life than ECR or uncoated galvanized rebar, further tests are needed. Some preliminary tests have shown that the life of bridge decks constructed with this product will be longer than any product except stainless steel (Clemena, et.al. 2004).

However, the tests were not done with uncoated steel in the same placement. Since many actual bridge decks have uncoated shear studs, defects in the epoxy coating could create a site for accelerated corrosion.

This product would appear to have all the same limitations as ECR or galvanized rebar, such as poor bond, fragile coating, variations in coating thickness, etc.

Microcomposite Multistructural Formable (MMFX 2) Steel

This proprietary alloy is a low-carbon, 9% chromium alloy with unusually high tensile mechanical properties. Tests have shown that it provides significantly longer life than uncoated carbon steel reinforcing bar, and will probably provide longer life than ECR or galvanized steel (Clemena, et.al. 2004). Some states now accept this material as a substitute for ECR, and some have discontinued the use of ECR entirely in favor of MMFX 2 or other materials with longer life.

While data is incomplete, it appears that an HPC deck, in conjunction with the use of MMFX 2 reinforcing bar, will have a life in the range of 30 to 50 years. Advantages of MMFX 2 include a good bond to the cement paste (compared to ECR), no problems with handling a fragile coating, and a higher yield at 0.2% deformation. Disadvantages include a sole source, poor ductility, and higher initial costs than ECR or galvanizing.

Fiber Reinforced Plastic (FRP) Rebar

This is the most recently developed material. It has been used in a few experimental structures. While the material itself will never corrode, it does have a limited life span. FRP does lose strength with age, and most experts in this field estimate a life of 65 to 90 years in service conditions before the loss of strength is unacceptable (GangaRao, 2007). The principal problems with FRP reinforcing bar are high initial cost, low elastic modulus (generally requiring FRP to be used at least one size larger in deck designs), impossibility of bending (requiring prefabricated bends spliced to straight bars), and poorer bond with cement paste (comparable to ECR).

Another unanswered question with FRP is the value of thermal conductivity. Most designers have assumed that reinforcing bar serves several purposes: structural strength, crack control, and equalizing temperature (to reduce thermal stress). FRP reinforcing bar has much lower thermal conductivity than any metal and will not equalize thermal stress as well as metal reinforcing. The authors have found no research on the probability of cracking from thermal stresses when non-conducting reinforcing bar is used.

Stainless Steel Clad Rebar

Two companies, one in the United Kingdom and one in the United States, have produced carbon steel rebar with a stainless steel cladding in recent years. This material has the potential of providing comparable life to solid stainless steel at lower cost. Tests have shown that the only deterioration that occurs in this material is at the cut ends (Clemena, et.al, 2004), which must be capped to avoid corrosion of the carbon steel base.

However, its principal disadvantage is its limited availability. The only U.S. plant is not currently in production, and the U.K.-produced material may not be used on federally funded highway projects in the United States. Since the clad material is not readily available at this time, it is not practical for designers to specify it, and it will not be considered further here.

Solid Stainless Steel Rebar

Solid stainless steel reinforcing bar has been used successfully in very corrosive environments for more than 70 years. In 1937, the Progreso Port Authority, in the Port of Progreso, Yucatan, Mexico, constructed a bridge using stainless reinforcing rebar, AISI Type 304, due to the aggressive chloride environment of the saltwater where this bridge was built. Almost 70 years later, this bridge is still standing and being used daily. According to the local authorities, this bridge has not had to undergo any type of major repair work throughout the life of this structure. A sister bridge, built to offset the heavy traffic flow in this area, was constructed in the 1960's using standard carbon steel rebar. That bridge has been out of service for many years because the deck and foundation have almost completely disintegrated, due to a complete loss of the carbon steel reinforcing bar.

Tests by the FHWA and various states show that solid stainless steel reinforcing bar will last at least 100 years in typical northern state conditions (McDonald, et.al., 1998). The most commonly used alloys today are Type 316LN and Type 2205, which have significantly better corrosion resistance than Type 304. Even though uncoated solid stainless steel rebar is exposed to potential differences between mats, the corrosion threshold is an order of magnitude higher than for carbon steel. Some tests with a stainless steel top mat and an uncoated carbon steel bottom mat showed that the top mat actually became slightly anodic, and the bottom mat corroded while the top mat was undamaged.

The obvious advantages of solid stainless steel reinforcing bar are extremely long life, excellent corrosion resistance and high strength with good ductility, good bond to the cement, no fragile coating, and no need of end caps. The disadvantage is the expense of the higher initial cost. Typically, solid stainless steel costs 2.5 to 4.0 times the cost of carbon steel. However, new design life requirements, such as 100+ years, demand that bridge engineers evaluate both the overall construction costs and the total life cycle costs, as they decide what materials will give them their best option. With maintenance and replacement costs measured in billions of dollars, due to the corrosion of carbon steel reinforcing bar in the United States, the total life cycle cost of bridge and highway structures should far outweigh the initial cost of materials.

Recently, Talley Metals, a Carpenter Technology Corporation company, introduced a new, lower-cost stainless steel alloy, EnduraMet® 32 stainless, which has been used for concrete reinforcing bar. Corrosion resistance and most structural properties are similar to AISI 316LN or 2205. However, the low nickel and its metallurgically balanced alloy content reduces its cost dramatically. Typical purchase costs for EnduraMet® 32 stainless are from 1.5 to 2.0 times the cost of carbon steel, or about one half the cost of AISI 316LN or 2205.

The standard specification that covers stainless steel reinforcing bar is ASTM A-955, and EnduraMet® 32 stainless meets all the strength requirements of the various grade levels and far exceeds the ductility requirements, making it easy to form while maintaining its superior strength. Corrosion macrocell testing, which measures the corrosion rate of steel rebar, including stainless, in a simulated concrete pore solution, has demonstrated that EnduraMet® 32 stainless far exceeds the proposed ASTM requirement of 0.25µm/year average by attaining 0.015µm/year average in a 15 week test period.

The FHWA's slogan, "Get in, Get out, and Stay out," which is commonly used in describing the need to minimize any disruptions to traffic flow, is intended to improve the public's perception regarding the rehabilitation of road and bridge structures. The use of solid stainless reinforcing bar, in critical bridge decks and components will significantly improve the life of these structures, thus meeting the FHWA's intention.

Comparison of Alternatives

Bridge designers have the choice of various types of reinforcing bar as outlined above. The choice of material will depend on life span, reliability, and economic issues such as initial capital cost and total life cycle cost.

New bridges in most states today are designed for a 75 year life span, and some major structures are designed for a century or more. In the past, most bridge agencies have accepted the fact that a 75-year bridge will require at least one major rehabilitation during that period. However, especially in urban areas, major rehabilitations have proven to be very expensive and have caused substantial disruptions to normal traffic flow. Bridge owners have been looking for more durable materials, and some of the materials described above can provide substantially longer life at relatively low cost.

FRP reinforcing and the various solid stainless steel options all can provide bridge deck with a life span of 75 years or more. The "Zn-ECR" material may achieve this life span, but more testing will be needed. However, when a designer considers other structural properties such as bond to the cement paste, the FRP and Zn-ECR materials are no better than "conventional" ECR. The solid stainless steel reinforcing bar options alone have the durability to last more than 75 years (and most could last more than 100 years), and all can deliver optimum structural properties.

As noted above, the stainless steel options may have the highest costs. Bridge designers cannot arbitrarily select a more expensive material just because it will last longer. Most agencies use life-cycle cost comparisons when selecting different materials for bridges (and highways), and this practice is encouraged by FHWA. The section below is intended to illustrate the economic comparisons between selected rebar options and to give guidance to bridge designers when they are selecting materials for new bridges and for major bridge or roadway rehabilitations.

ECONOMIC COMPARISONS

Most decisions to use materials with more or less durability are based on cost. Since the projected life of concrete bridge elements is always greater than 25 years, a simple cost comparison cannot be used. The FHWA and most state agencies use a life-cycle cost comparison, using an estimated discount rate based on interest minus inflation. Historically, this rate has always been near 4%, and that figure will be used throughout this paper.

As noted above, a well constructed HPC deck with ECR in top and bottom mats can reasonably be expected to last 35 to 50 years in most northern states. An identical deck with solid stainless reinforcing could last as much as 120 years, but no one has projected the life of the concrete itself that far.

Current costs for both carbon steel and stainless steel are rising rapidly. The best available figures today are that the purchase cost of stainless steel (AISI 316 or 2205) will be about 2.5 to 4.0 times the purchase cost of carbon steel. Placement costs are virtually identical. In the New York City area, rebar placement cost is generally equal to the purchase cost of the carbon steel. Thus, in the NYC area, in place costs for solid stainless steel are 1.75 to 2.25 times the cost for ECR.

The price of deck reinforcing (ECR) generally represents about 10% to 14% of the cost of the entire bridge deck. Assuming the average of 12% for ECR, solid stainless steel would represent an increase in cost of 9% to 15% of the entire deck, compared to ECR.

Assume that a bridge deck constructed with ECR will last 40 years and will then be replaced at current costs. The present worth of the 40-year replacement is equal to 20.83% of the cost of the deck today. However, the cost of related construction items such as demolition, barriers, railing, joints, and maintenance & protection of traffic must be added to the deck costs. If the related elements add about 25% to the deck costs, the present worth of the 40-year replacement is 26.04% of the cost of today's construction. This compares favorably with the 9% to 15% increase in costs to use solid stainless steel instead of ECR.

Obviously, in highly congested areas such as central city arterials, maintenance and protection of traffic costs are unusually high. The high cost of detours and the high cost of deck repairs that become necessary near the end of the life of the deck make the comparison even more favorable to the stainless steel reinforcing.

The following table illustrates the relative cost of new bridge decks constructed with ECR (or galvanized rebar), MMFX 2 material, FRP, Solid Stainless, and EnduraMet® 32 stainless. While the longer-lived options (FRP and stainless) have a higher initial cost, the life cycle costs of these decks are actually lower than the "conventional" ECR deck.

TABLE 1 | COMPARISON OF INITIAL COST AND LIFE CYCLE COSTS OF BRIDGE DECKS WITH VARIOUS TYPES OF REINFORCING

REINFORCING TYPE	ECR, GALVANIZED	MMFX 2	FRP	SOLID STAINLESS	ENDURAMET® 32 STAINLESS
Initial deck cost (compared to ECR)	100.00%	103.00%	106.00%	112.00%	106.00%
Estimated life (yrs.)	40	50	65	100	100
Present worth of deck replacement at end of life	26.04%	18.12%	10.35%	2.77%	2.10%
100-year life cycle cost as a percentage of initial cost of ECR deck	130.22%	121.12%	115.21%	114.77%	108.62%

DESIGN ASSUMPTIONS

1. Present worth of deck replacement and 100-year life cycle costs assume 25% for related costs of replacement (M&PT, demolition, etc.).
2. 100-year life cycle cost assumes replacement with identical deck design at end of each life span. Remaining salvage value at 100 years is deducted.
3. FRP values assume equivalent linear quantities, with all bars 1 size larger than steel bars.
4. "Solid stainless" assumes AISI 316LN or 2205.

DESIGN IMPROVEMENTS AVAILABLE WITH NON-CORROSIVE REINFORCING

All the comparisons above assume that all decks are designed identically, using the Standard Specifications for Highway Bridges or "empirical" methods. However, the use of non-corroding reinforcing will allow design savings in other areas.

Reduced Deck Thickness

Most bridge owners require a minimum cover over the top mat of reinforcing between 50 mm (2 in.) and 75 mm (3 in.). The common standard in many U.S. states is 62 mm (2.5 in.) while New York requires 75 mm (3 in.). New York also allows a designer to reduce the top mat cover by 25 mm (1 in.) if non-corroding reinforcing is used in the top mat. Since NYSDOT's "standard" bridge deck with ECR is 240 mm (9.5 in.) thick, the use of non-corroding reinforcing allows a reduction in deck concrete volume of 10.52%, with a corresponding reduction in dead load of the deck.

Concrete material and placing costs represent about 9% to 10% of the cost of a bridge deck. Thus, the 10.42% reduction in thickness will reduce the initial cost of the deck by approximately 1%. Since the cover over the top steel is not included in the flexural design of the deck, there is no loss in structural capacity from the reduced slab thickness.

Reduction in dead weight of the deck will reduce the total dead load of the structure. For a typical multi-span continuous steel plate girder structure with spans in the range of 60 m (200 ft.), the deck dead load represents about 65% of the total dead load, and about 40% to 45% of the total dead plus live load. The demand on the girders will thus be reduced by about 4%. For the more common continuous structures, this analysis assumes that there will be very little savings of structural steel in the positive moment areas, because the reduction in deck thickness will effectively reduce the area of the composite girder flange. However, since composite action is not assumed in negative moment areas, a savings comparable to the reduction in demand will be achieved in those areas.

The following analysis assumes a 4.45% reduction in demand on the girders in negative moment areas only, and an equivalent reduction in structural steel cost in those areas.

TABLE 2 | COMPARISON OF INITIAL COST AND LIFE CYCLE COSTS OF NEW BRIDGES WITH VARIOUS TYPES OF DECK REINFORCING

REINFORCING TYPE	ECR, GALVANIZED	MMFX 2	FRP	SOLID STAINLESS	ENDURAMET® 32 STAINLESS
Deck cost (compared to total initial cost of "base" structure)	38.00%	39.14%	39.90%	42.18%	39.90%
Steel cost (compared to total initial cost of "base" structure)	31.00%	31.00%	30.50%	30.50%	30.50%
Foundation cost (compared to total initial cost of "base" structure)	25.00%	25.00%	25.00%	25.00%	25.00%
Earthwork, etc. cost (compared to total initial cost of "base" structure)	6.00%	6.00%	6.00%	6.00%	6.00%
Total initial cost of structure	100.00%	101.14%	101.40%	103.68%	101.40%
Estimated Life (years)	40	50	65	100	100
Present worth of deck replacement at end of life	9.89%	6.88%	3.93%	1.05%	1.00%
100-year life cycle cost as a percentage of initial cost of "base" structure	111.48%	108.02%	104.88%	104.74%	102.40%

DESIGN ASSUMPTIONS

1. DL of structural steel is 50% of DL of concrete (std. deck).
2. Deck cost is 38% of the cost of the "base" structure.
3. Steel cost is 31% of the cost of the "base" structure.
4. Foundation is 25% of the cost of the "base" structure.
5. Earthwork & misc. is 6% of the cost of the "base" structure.
6. DL of concrete reduced 10.5% by reduction of deck thickness.
7. Cost of deck is reduced 1.0% by reduced thickness.
8. Total DL is reduced by 7.0%.
9. Total DL + LL + I is reduced by 4.45%.
10. Demand on girders in negative moment areas is reduced by 4.45%.
11. Flange thickness of girders in negative moment areas is reduced by 4.45%.
12. Self weight of steel in negative moment areas is reduced by 4.0%.
13. Negative moment areas represent 40% of entire structure.
14. Total weight and cost of structural steel is reduced by 1.6%.
15. No reduction in foundation costs from reduced DL.
16. Other assumptions same as Table 1.

Table 2 shows that a bridge using EnduraMet® 32 stainless in the deck will have an initial cost only 1.4% higher than the same bridge using ECR, when the savings in structural steel are computed. Higher savings in structural steel could actually reduce the higher initial cost for EnduraMet® 32 stainless, but it is unlikely that the net initial cost difference could be reduced to zero, unless other savings can be found.

Reduced Foundation Costs

Table 2 assumes that there are no improvements in foundation design available from the reduction in dead load. In many cases, that is a valid assumption. However, for structures in poor soils, especially where high foundations are used, the reduction total dead load plus live load will provide savings in foundation design, especially where the foundation is governed by seismic loads.

A reduction in dead load of a superstructure supported by a tall pier can substantially reduce the seismic demand on that pier. This reduction can reduce the size of the pier column and can also reduce the size and cost of the footing or pile cap. The number of piles can sometimes be reduced.

Table 3 assumes that the 4.0% savings in superstructure cost is achieved in foundation cost also. This is obviously an arbitrary assumption: foundation savings in many structures will be very small, while a structure with tall column piers in very poor soil may achieve savings in the range of 5% to 8%. When designing structures in these conditions, designers should consider various methods of reducing weight, including non-corrosive reinforcing, lightweight concrete, etc.

TABLE 3 | COMPARISON OF INITIAL COST AND LIFE CYCLE COSTS OF NEW BRIDGES WITH VARIOUS TYPES OF DECK REINFORCING

REINFORCING TYPE	ECR, GALVANIZED	MMFX 2	FRP	SOLID STAINLESS	ENDURAMET® 32 STAINLESS
Deck cost (compared to total initial cost of "base" structure)	38.00%	39.14%	39.90%	42.18%	39.90%
Steel cost (compared to total initial cost of "base" structure)	31.00%	31.00%	30.50%	30.50%	30.50%
Foundation cost (compared to total initial cost of "base" structure)	25.00%	25.00%	24.00%	24.00%	24.00%
Earthwork, etc. cost (compared to total initial cost of "base" structure)	6.00%	6.00%	6.00%	6.00%	6.00%
Total initial cost of structure	100.00%	101.14%	100.40%	102.68%	100.40%
Estimated Life (years)	40	50	65	100	100
Present worth of deck replacement at end of life	9.89%	6.88%	3.93%	1.05%	1.00%
100-year life cycle cost as a percentage of initial cost of "base" structure	111.48%	108.02%	103.88%	103.74%	101.40%

DESIGN ASSUMPTIONS

1. Foundation cost reduced by 4.0% where DL is reduced by 7.0%.
2. All other assumptions same as Tables 1 and 2.

Table 3 is identical to Table 2 except for the reduced foundation costs for the FRP, Solid Stainless, and EnduraMet® 32 stainless options. For solid stainless steel (AISI 316 or 2205), a 15% reduction in foundation costs would actually reduce the total initial cost of a structure using solid stainless tell rebar below the "base" structure. While this is unlikely, except possibly in extremely poor soil conditions, the reduction in superstructure dead load can provide substantial reduction in cost for the entire structure. For EnduraMet® 32 stainless, a 7% reduction in foundation costs will reduce the total initial cost of the structure below the initial cost of the "base" structure using ECR in the deck. While this reduction in foundation cost will not be available on the average highway bridge, it could be achieved in some cases.

USE OF STAINLESS STEEL REINFORCING IN FOUNDATIONS

Stainless steel reinforcing is not commonly specified in bridge supports such as columns or stem piers, but designers may want to consider several options. Foundation structures vary so widely that precise comparisons can be difficult to quantify. The following discussion is based on a "common" bridge support column in a marine environment (footing or pile cap in sea water). The “sample” column is 48 inches square, contains 36 #11 vertical bars (10 per side), and uses #4 ties at 6” o.c. vertically. Cover is 4”, which is required by many agencies for structures in sea water.

If solid stainless steel reinforcing is used, the designer has the choice of reducing the cover to 2” or relocating the vertical bars closer to the original surface. Relocating the vertical bars closer to the surface will increase the capacity of the column without increasing weight or size. Reducing the cover while maintaining the position of the bars will not affect the original capacity but will reduce the size and weight of the column. The following table illustrates the relative costs and benefits of these options:

TABLE 4 | COMPARISON OF COLUMN DESIGNS WITH VARIOUS TYPES OF REINFORCING

COLUMN DESCRIPTION	COST INCREASE	CAPACITY INCREASE	DEAD LOAD CHANGE
48" x 48", ECR, 4" cover			
52" x 52", ECR, 4" cover	11.4%	20.1%	17.4%
48" x 48", SS (316LN), 2" cover	48.0%	20.1%	0.0%
48" x 48", SS (EnduraMet® 32 stainless), 2" cover	24.0%	20.1%	0.0%
44" x 44", SS (316LN), 2" cover	37.1%	0.0%	-16.0%
44" x 44", SS (EnduraMet 32® stainless), 2" cover	13.3%	0.0%	-16.0%

DESIGN ASSUMPTIONS

1. Cover is reduced by 2" using solid stainless rebar.
2. A 1" decrease in the deck thickness occurs using solid stainless rebar.
3. The life of the column may exceed 100 years.
4. The DL is reduced by 16%.
5. A corresponding decrease in the cost of the supporting foundation may occur.
6. Column size, i.e. cross section, is reduced by 16%.

The table shows that a designer who needs to increase the capacity of the “basic” column can simply increase the size, with a cost increase of 11.4% and a dead load increase of 17.4%. The dead load increase will affect the cost of the supporting foundation, but this cannot be quantified here. A designer who needs to increase the capacity of the basic column but cannot accept the increased dead load can accomplish that goal by specifying stainless steel reinforcing at reduced cover. The cost of the column could increase by 48% (316LN stainless) or by 24% (EnduraMet® 32 stainless) but with no other increase in costs. The life of the column can be expected to exceed 100 years.

If a designer wants to extend the life of a column but its capacity is adequate, the size can be reduced by using stainless steel reinforcing. The cost of the column will be increased by 37.1% (316LN) or 13.3% (EnduraMet® 32), and the capacity will remain unchanged. The dead load will be reduced by 16%, and there may be a corresponding decrease in the cost of the supporting foundation.

EXAMPLES

The New York State Department of Transportation is presently designing two bridge rehabilitation projects using solid stainless steel reinforcing in the deck. Each bridge has some unusual circumstances. In each case, the additional cost of solid stainless steel (combined with lightweight concrete in one case) can be completely offset by resulting design efficiencies elsewhere in the project.

Alexander Hamilton Bridge

This steel riveted spandrel arch bridge carries I-95 across the Harlem River. Approach spans are steel multi-girder. The scope of the project is deck replacement, widening, steel rehabilitation, and seismic upgrades.

The increased dead load would have required substantial reinforcement of the existing riveted steel spandrel arch ribs and spandrel columns. The weight savings achieved by the use of stainless steel reinforcing have made most of this reinforcement unnecessary. Not only will the total cost of construction be reduced as a result of using stainless steel, but construction time will be reduced by approximately six months.

Undercliff Avenue Bridge

A related project is the Undercliff Avenue Bridge, which carries a local street over the eastern approach to the Alexander Hamilton Bridge. Because of constrained highway profiles, the replacement structure must span more than 100 feet with welded plate girders 32 inches deep. This uneconomic section will require girder spacing of less than 6 feet.

The use of stainless steel reinforcing has allowed a 1 inch savings in deck thickness to be applied to the girder depth. Adding 1 inch to the girder depth has enabled the designers to eliminate one of the girders in the original design, resulting in lower overall cost of the project.

Major Deegan Expressway Viaduct

This is a 72-span, steel riveted viaduct carrying I-87 over local streets near Yankee Stadium. The scope of work is deck replacement, widening, steel rehabilitation, and seismic upgrades.

The widening of the structure – required for highway geometry and for maintenance of traffic during construction – would have required 16 new pile-supported foundations. The use of stainless steel reinforcing and lightweight concrete in the new deck has made those foundations unnecessary and has also substantially reduced the cost of the seismic upgrades.

CONCLUSION

The use of carbon steel reinforcing bar has been common for more than 100 years. Recent advances in materials will provide superior durability and reduced life cycle costs compared to carbon steel, even when epoxy coated or galvanized. Some more modern materials, such as solid stainless steel reinforcing bar, will actually provide a reduced total cost of a new bridge structure in specific cases while providing longer life, at no additional cost.

The various relative costs and percentages given above are based on specific assumptions, which the authors believe are representative of typical bridge projects. These assumptions will obviously not be valid for all cases. This paper is intended to illustrate that choosing the more expensive material does not always result in a more expensive project. The economic savings available from the use of better materials can frequently offset the higher initial cost of those materials, when one employs the use of full life cycle cost analysis.

The examples above are unusual, but they illustrate that the use of more expensive and longer-lasting materials may not actually increase the initial cost of a bridge project. In all three cases, the increased cost of the stainless steel reinforcing will be completely offset by savings elsewhere. The longer life of the stainless reinforcing is essentially “free” to the owner and the taxpaying public.

Bridge designers should evaluate different reinforcing materials during the design of major rehabilitation projects, as well as any new bridge project. A project involving deck replacement and steel repair on a deteriorated bridge could use the design advantages of corrosion resistant reinforcing bar to reduce the cost of steel repairs. The weight savings can substantially reduce the cost of a seismic upgrade for an older bridge that is being rehabilitated. The methodology used here can be used by designers to determine the economic value of various design options on many bridge projects.

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Technical Datasheet

CARPENTER

EnduraMet® 32 Stainless

UNS Number

- S24100

Type Analysis

Carbon (Maximum)	0.06 %	Manganese	11.00 to 14.00 %
Phosphorus (Maximum)	0.060 %	Sulfur (Maximum)	0.030 %
Silicon (Maximum)	1.00 %	Chromium	16.50 to 19.00 %
Nickel	0.50 to 2.50 %	Nitrogen	0.20 to 0.45 %
Iron	Balance		

Description

EnduraMet® 32 stainless is a high-manganese, low-nickel, nitrogen-strengthened austenitic stainless steel. By means of solid solution strengthening, the nitrogen provides significantly higher yield and tensile strength as annealed than conventional austenitic stainless steels such as Type 304 and Type 316, without adversely affecting ductility, corrosion resistance or non-magnetic properties. In the hot rolled unannealed condition, yield strengths of 75 ksi (518 MPa) or higher can be achieved for bar diameters up to 2 in. (50.8 mm).

Applications

EnduraMet 32 stainless may be considered for rebar in bridge decks, barrier and retaining walls, anchoring systems, chemical plant infrastructure, coastal piers and wharves, bridge parapets, sidewalks and bridge pilings. Because of its low magnetic permeability, EnduraMet 32 may also be considered for concrete rebar applications in close proximity to sensitive electronic devices and magnetic resonance medical equipment. The higher strength capability, 75 ksi (518 MPa) minimum yield strength, of EnduraMet 32 is an added economical advantage.

EnduraMet 32 may also be considered for dowel bars, welded-wire mesh and tie wire.

Scaling

The safe scaling temperature for continuous service is 1600ºF (871ºC).

Corrosion Resistance

EnduraMet 32 stainless has good resistance to atmospheric corrosion and long-term resistance to general corrosion when embedded in concrete. In the 15 week corrosion macrocell test in simulated concrete pore solution, EnduraMet 32 stainless had an average corrosion rate less than 0.25 micro-meter/yr.

Intergranular corrosion may be a problem if the material is heated between 800ºF (427ºC) and 1650ºF (899ºC) or cooled slowly through that range.

For optimum corrosion resistance, surfaces must be free of scale, lubricants, foreign particles, and coatings applied for drawing and heading. After fabrication of parts, cleaning and/or passivation should be considered.

Important Note: *The following 4-level rating scale is intended for comparative purposes only. Corrosion testing is recommended; factors which affect corrosion resistance include temperature, concentration, pH, impurities, aeration, velocity, crevices, deposits, metallurgical condition, stress, surface finish and dissimilar metal contact.*

Nitric Acid	Good	Sulfuric Acid	Restricted
Phosphoric Acid	Restricted	Acetic Acid	Moderate
Sodium Hydroxide	Moderate	Salt Spray (NaCl)	Good
Humidity	Excellent	Sour Oil/Gas	N/A

Physical Properties

Specific Gravity	7.75	
Density	0.2800 lb/in^3	7750 Kg/m^3
Mean Coefficient of Thermal Expansion 70.0/1000°F, 21.11/537.8°C	10.3 x 10^{-6} in/in/°F	18.5 x 10^{-6} cm/cm/°C
Modulus of Elasticity (E)	29.0 x 10^3 ksi	200 x 10^3 MPa
Electrical Resistivity 70.0°F, 21.1°C	421.0 ohm-cir-mil/ft	699.7 micro-ohm-mm
Magnetic Permeability Annealed, 200 Oe, 15900 A/m	1.0100 Mu	1.0100 Mu
Cold Drawn 70%, 200 Oe/15900 A/m	1.0200 Mu	1.0200 Mu

Heat Treatment

Annealing

Heat to 1900/1950ºF (1038/1066ºC) and water quench, or rapidly cool as with other austenitic stainless steels. Typical hardness as annealed is approximately Rockwell B 95.

Hardening

Cannot be hardened by heat treatment; however, high strength can be achieved by thermal mechanical processing. Can be hardened by cold work as well.

Workability

Hot Working

EnduraMet 32 stainless can be forged, hot-rolled, hot-headed and upset. Because of its higher strength, greater force than for Type 304 is required. For hot working, heat uniformly to 2100/2200ºF (1149/1204ºC). Preheating to an intermediate temperature is not required. For rebar, a controlled hot rolling practice is used.

Cold Working

EnduraMet 32 stainless can be cold formed by drawing, bending, upsetting and stamping. Because of its higher strength and work-hardening rate, the force required is greater than for Types 302, 304 or 316. The high work-hardening rate can be used to advantage when cold working to increase strength; i.e., less reduction is required to achieve high levels of strength.

Machinability
EnduraMet 32 stainless has a machinability rating about 41% of AISI 1212. Slow to moderate speeds, moderate feeds and rigid tools should be considered. Chips tend to be tough and stringy. Chip curlers or breakers are helpful. Use a sulfurized cutting fluid, preferable of the chlorinated type.

Following are typical feeds and speeds for EnduraMet 32.

Typical Machining Speeds and Feeds – EnduraMet 32 Stainless
The speeds and feeds in the following charts are conservative recommendations for initial setup. Higher speeds and feeds may be attainable depending on machining environment.

Turning—Single-Point and Box Tools

Depth of Cut (Inches)	Micro-Melt® Powder High Speed Tools			Carbide Tools (Inserts)			
	Tool Material	Speed (fpm)	Feed (ipr)	Tool Material	Speed (fpm) Uncoated	Speed (fpm) Coated	Feed (ipr)
.150	M48, T15	72	.015	C6	250	300	.015
.025	M48, T15	84	.007	C7	300	350	.007

Turning—Cut-Off and Form Tools

Tool Material: Micro-Melt® Powder HS Tools	Tool Material: Carbide Tools	Speed (fpm)	Feed (ipr) Cut-Off Tool Width (Inches) 1/16	1/8	1/4	1/2	Feed (ipr) Form Tool Width (Inches) 1	1 ½	2
M48, T15		54	.001	.001	.0015	0015	.001	.0007	.0007
	C6	192	.004	.0055	.004	.004	.003	.002	.002

Rough Reaming

Micro-Melt® Powder High Speed Tools		Carbide Tools		Feed (ipr) Reamer Diameter (inches)					
Tool Material	Speed (fpm)	Tool Material	Speed (fpm)	1/8	1/4	1/2	1	1 ½	2
M48, T15	72	C2	80	.003	.005	.008	.012	.015	.018

Drilling

High Speed Tools									
Tool Material	Speed (fpm)	Feed (inches per revolution) Nominal Hole Diameter (inches) 1/16	1/8	1/4	1/2	3/4	1	1 ½	2
M42	45-55	.001	.002	.004	.007	.010	.012	.015	.018
C2 Coated	140	.0005	.002	.004	.006	.0077	.0088	.0098	.0098

Die Threading

FPM for High Speed Tools				
Tool Material	7 or less, tpi	8 to 15, tpi	16 to 24, tpi	25 and up, tpi
T15, M42	4-8	6-10	8-12	10-15

Milling, End-Peripheral

Depth of Cut (inches)	Micro-Melt® Powder High Speed Tools: Tool Material	Speed (fpm)	Feed (ipt) Cutter Diameter (in) 1/4	1/2	3/4	1-2	Carbide Tools: Tool Material	Speed (fpm)	Feed (ipt) Cutter Diameter (in) 1/4	1/2	3/4	1-2
.050	M48,T15	78	.001	.002	.003	.004	C2	245	.001	.002	.003	.005

Tapping

High Speed Tools	
Tool Material	Speed (fpm)
M7, M10	12-25

Broaching

Micro-Melt® Powder High Speed Tools		
Tool Material	Speed (fpm)	Chip Load (ipt)
M48, T15	12	.0030

Additional Machinability Notes
When using carbide tools, surface speed feet/minute (sfpm) can be increased between 2 and 3 times over the high speed suggestions. Feeds can be increased between 50 and 100%.

Figures used for all metal removal operations covered are starting points. On certain work, the nature of the part may require adjustment of speeds and feeds. Each job has to be developed for best production results with optimum tool life. Speeds or feeds should be increased or decreased in small steps.

Weldability
EnduraMet 32 stainless can be satisfactorily welded by the shielded fusion and resistance welding processes. Oxyacetylene welding is not recommended, since carbon pickup in the weld may occur. Since austenitic welds do not harden on air cooling, the welds should have good toughness.

When a filler metal is required, consider using a welding consumable with a matching analysis to EnduraMet 32 or AWS E/ER240. Both should provide welds with strength approaching that of the base metal. If high weld strength is not necessary, then consider AWS E/ER 308.

Post-weld annealing is not required for most applications but can provide optimum properties for severe service.

Typical Mechanical Properties

Typical Room Temperature Hot Rolled Mechanical Properties – EnduraMet 32 Stainless
Samples were full-section rebar

Bar Size		Rebar #	0.2% Yield Strength		Ultimate Tensile Strength		% Elongation in 8" (203 mm)
in	mm		ksi	MPa	ksi	MPa	
0.625	15.9	5	81	559	118	814	40.0
1.000	25.4	8	84	580	121	835	42.0

Applicable Specifications

Note: While this material meets the following specifications, it may be capable of meeting or being manufactured to meet other general and customer-specific specifications.

- ASTM A276 (Grade XM-28)
- ASTM A313 (Grade XM-28)
- ASTM A580 (Grade XM-28)
- ASTM A955 (Grade XM-28)

Forms Manufactured

- Bar-Rounds
- Rebar or (Bar-Reinforcing)
- Wire

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EnduraMet® 2205 Stainless

UNS Number

- S31803

DIN Number

1.4662

Type Analysis

Carbon (Maximum)	0.03 %	Manganese (Maximum)	2.0 %
Phosphorus (Maximum)	0.030 %	Sulfur (Maximum)	0.020 %
Silicon (Maximum)	1.00 %	Chromium	21.00 to 23.00 %
Nickel	4.50 to 6.50 %	Molybdenum	2.50 to 3.50 %
Nitrogen	0.08 to 0.20 %	Iron	Balance

Description

EnduraMet® 2205 stainless is a duplex stainless steel that has a microstructure consisting of austenite and ferrite phases. This duplex microstructure and the chemical composition of EnduraMet 2205 stainless results in an excellent combination of strength and corrosion resistance.

EnduraMet 2205 stainless has twice the annealed yield strength of typical austenitic stainless steels, like Type 304 and 316. In the hot rolled unannealed condition, yield strength of 75 ksi (518 MPa) or higher can be achieved for bar diameters up to 1.375 in. (34.925mm).

EnduraMet 2205 stainless possesses good resistance to general corrosion in many acid environments and, has excellent resistance to chloride stress corrosion cracking, pitting and crevice corrosion.

Applications

Rebar has been a primary application for EnduraMet 2205 stainless. Specific rebar applications have included bridge decks, barrier and retaining walls, anchoring systems, chemical plant infrastructure, coastal piers and wharves, bridge parapets, sidewalks and bridge piling. The higher strength capability, 75 ksi (518 MPa) minimum yield strength, of EnduraMet 2205 stainless rebar is an added economical advantage.

Other applications for EnduraMet 2205 stainless have included bridge tie wire and dowels; oil and gas production equipment, such as valves, fittings, shafts, and pump parts; heat exchangers in chemical and pulp and paper plants; and brewery tanks.

Elevated Temperature Use

EnduraMet 2205 stainless is subject to 885 embrittlement when exposed for extended times between about 700 and 1000°F (371 and 538°C).

The alloy is also subject to precipitation of sigma phase when exposed between about 1250 and 1550°F (677 and 843°C) for extended time. Sigma phase increases strength and hardness, but decreases ductility and corrosion resistance.

Corrosion Resistance

Compared to conventional austenitic stainless steels, like Type 304 and 316, EnduraMet 2205 stainless has superior resistance in most oxidizing and reducing acids; superior chloride pitting and crevice corrosion resistance, due to higher chromium, molybdenum and nitrogen content and superior resistance to chloride stress corrosion cracking due to its duplex microstructure.

EnduraMet 2205 has good intergranular corrosion in the as-annealed and as-weld conditions due to its low carbon content. Some intergranular attack may occur in the hot rolled unannealed condition.

For optimum corrosion resistance, surfaces must be free of scale, lubricants, foreign particles, and coatings applied for drawing and heading. After fabrication of parts, cleaning and/or passivation should be considered.

Important Note: *The following 4-level rating scale is intended for comparative purposes only. Corrosion testing is recommended; factors which affect corrosion resistance include temperature, concentration, pH, impurities, aeration, velocity, crevices, deposits, metallurgical condition, stress, surface finish and dissimilar metal contact.*

Nitric Acid	Good	Sulfuric Acid	Moderate
Phosphoric Acid	Moderate	Acetic Acid	Good
Sodium Hydroxide	Moderate	Salt Spray (NaCl)	Excellent
Sea Water	Moderate	Sour Oil/Gas	Moderate
Humidity	Excellent		

Physical Properties

Specific Gravity		
As Rolled	7.82	
Annealed	7.80	
Density		
As Rolled	0.283 lb/in^3	7820 Kg/m^3
Annealed	0.282 lb/in^3	7800 Kg/m^3

Mean Coefficient of Thermal Expansion – EnduraMet 2205 Stainless
0.5" (12.5 mm) diameter rebar

Test Temperature		Hot Rolled Condition		Annealed Condition	
77°F to	25°C to	10^{-6}/°F	10^{-6}/°C	10^{-6}/°F	10^{-6}/°C
122	50	7.02	12.64	6.22	11.20
212	100	7.48	13.47	7.11	12.48
302	150	7.70	13.86	7.29	13.12
392	200	7.82	14.07	7.53	13.56
482	250	8.04	14.47	7.72	13.89
572	300	8.17	14.71	7.86	14.14
662	350	8.26	14.87	7.97	14.34
752	400	8.34	15.01	7.99	14.39
842	450	8.44	15.20	8.12	14.62
932	500	8.53	15.36	8.23	14.82
1012	550	8.57	15.42	8.30	14.94
1112	600	8.68	15.63	8.44	15.19
1202	650	8.78	15.81	8.57	15.42
1292	700	8.92	16.11	8.77	15.79

Annealed 1950°F (1066°C) for 1 hour and water quenched. Dilatometer specimens were .250" (6.4 mm) sq. x 2" (50.8 mm) long.

Magnetic Properties

In the annealed and hot rolled conditions, EnduraMet 2205 stainless is ferromagnetic.

Heat Treatment

Annealing
Heat to 1850/2050°F (1010/1121°C) and rapidly quench in water or air. Typical hardness as-annealed is HRC 20.

Hardening
Cannot be hardened by heat treatment. Can be hardened only by cold working.

Workability

Hot rolling and controlling the finishing temperature can strengthen EnduraMet 2205 stainless bar. After hot rolling, bars are not annealed.

Hot Working
Heat uniformly to 2000/2100°F (1093/1149°C). Reheat as often as necessary. Cool forgings in air.

Cold Working
Cold working increases strength and hardness. Work hardening rate is lower than Type 304; however, the annealed strength is significantly higher.

Machinability
The machinability of EnduraMet 2205 stainless generally has been between that of conventional Type 316 stainless and Carpenter 22Cr-13Ni-5Mn stainless.

The following chart includes typical machining parameters used to machine EnduraMet 2205. The data listed should be used as a guide for initial machine setup only.

Typical Machining Speeds and Feeds – EnduraMet 2205 Stainless
The speeds and feeds in the following charts are conservative recommendations for initial setup. Higher speeds and feeds may be attainable depending on machining environment.

Turning—Single-Point and Box Tools

Depth of Cut (Inches)	High Speed Tools			Carbide Tools (Inserts)			
	Tool Material	Speed (fpm)	Feed (ipr)	Tool Material	Speed (fpm) Uncoated	Speed (fpm) Coated	Feed (ipr)
.150	T15	85	.015	C2	350	450	.015
.025	M42	100	.007	C3	400	525	.007

Turning—Cut-Off and Form Tools

Tool Material		Speed (fpm)	Feed (ipr)						
			Cut-Off Tool Width (Inches)				Form Tool Width (Inches)		
High Speed Tools	Car-bide Tools		1/16	1/8	1/4	1/2	1	1½	2
M2		75	.001	.0015	.002	.0015	.001	.001	.001
	C2	275	.004	.0055	.007	.005	.004	.0035	.0035

Rough Reaming

High Speed		Carbide Tools		Feed (ipr) Reamer Diameter (Inches)					
Tool Material	Speed (fpm)	Tool Material	Speed (fpm)	1/8	1/4	1/2	1	1½	2
M7	70	C2	90	.003	.005	.008	.012	.015	.018

Workability continued

Drilling

High Speed Tools									
Tool Material	Speed (fpm)	Feed (inches per revolution) Nominal Hole Diameter (inches)							
		1/16	1/8	1/4	1/2	3/4	1	1 ½	2
M7, M10	50-60	.001	.002	.004	.007	.010	.012	.015	.018

Die Threading

FPM for High Speed Tools				
Tool Material	7 or less, tpi	8 to 15, tpi	16 to 24, tpi	25 and up, tpi
M1, M2, M7, M10	8-15	10-20	15-25	25-30

Milling, End-Peripheral

Depth of Cut (inches)	High Speed Tools						Carbide Tools					
	Tool Material	Speed (fpm)	Feed (ipt) Cutter Diameter (in)				Tool Material	Speed (fpm)	Feed (ipt) Cutter Diameter (in)			
			1/4	1/2	3/4	1-2			1/4	1/2	3/4	1-2
.050	M2, M7	75	.001	.002	.003	.004	C2	270	.001	.002	.003	.005

Tapping

High Speed Tools	
Tool Material	Speed (fpm)
M1, M7, M10	12-25

Broaching

High Speed Tools		
Tool Material	Speed (fpm)	Chip Load (ipt)
M2, M7	15	.003

When using carbide tools, surface speed feet/minute (SFPM) can be increased between 2 and 3 times over the high-speed suggestions. Feeds can be increased between 50% and 100%.

Figures used for all metal removal operations covered are average. On certain work, the nature of the part may require adjustment of speeds and feeds. Each job has to be developed for best production results with optimum tool life. Speeds or feeds should be increased or decreased in small steps.

Weldability

EnduraMet 2205 stainless has been welded using many of the standard electric arc welding processes. Autogeneous welding will increase the amount of ferrite present in the weldement and heat affected zone. When a filler metal is required, consider AWS E/ER 2209.

Oxyacetylene welding is not recommended, because carbon pickup in the weld may occur.

Postweld annealing is not required for most applications, but will provide optimum properties for severe service.

Typical Mechanical Properties

Typical Room Temperature Hot Rolled Mechanical Properties – EnduraMet 2205 Stainless

Samples were full-section rebar

Bar Size		Rebar #	0.2% Yield Strength		Ultimate Tensile Strength		% Elongation in 8” (203 mm)
in	mm		ksi	MPa	ksi	MPa	
0.5	12.7	4	92.5	638	126	869	26.8
0.625	15.9	5	90.5	624	126.5	873	29.7
0.750	19.1	6	90.0	621	120.5	831	29.0
1.250	31.8	10	86.0	593	120.0	828	28.3
1.375	34.9	11	86.0	593	119.0	814	31.8

Typical Mechanical Properties
continued

Mechanical Properties at Various Test Temperatures – EnduraMet 2205 Stainless
0.5" (12.5 mm) diameter rebar

	Test Temperature		0.2% Yield Strength		Ultimate Tensile Strength		% Elonga-tion in 4D	% Reduction of Area
	°F	°C	ksi	MPa	ksi	MPa		
As-Rolled	-100	-73	127	875	159	1100	63.0	80.5
Annealed	-100	-73	90	621	144	994	70.5	81.0
As-Rolled	70	21	97	670	131	903	42.3	84.3
Annealed	70	21	70	480	113	777	50.1	85.3
As-Rolled	400	204	75	519	106	728	35.6	81.6
Annealed	400	204	51	350	93	640	40.6	80.4

Annealed 1950°F (1066°C) for 1 hour and water quenched.
Standard 0.250" (6.4 mm) gage diameter tensile specimens.

CVN Impact Data at Various Test Temperatures – EnduraMet 2205 Stainless
0.5" (12.5 mm) diameter rebar

Condition	Test Temperature		Charpy V-Notch Impact Strength	
	°F	°C	ft-lbs	Joules
As-Rolled	70	21	92	125
Annealed	70	21	120	163
As-Rolled	32	0	90	122
Annealed	32	0	104	141
As-Rolled	-100	-73	89	121
Annealed	-100	-73	96	131

Annealed 1950°F (1066°C) for 1 hour and water quenched.
Sub-size specimens 0.197" x 0.394" (5 mm x 10 mm) per ASTM E23.

RR Moore Rotating Beam Fatigue Tests – EnduraMet 2205 Stainless
0.5" (12.5 mm) diameter rebar

Hot Rolled Condition			Annealed Condition		
Test Stress		Cycles to Fracture	Test Stress		Cycles to Fracture
ksi	MPa		ksi	MPa	
40	276	1.5×10^7 (NF)	35	242	2.1×10^7 NF
50	345	1.3×10^7 (NF)	50	345	1.3×10^7 NF
60	414	1.4×10^7 (NF)	60	414	1.4×10^7 NF
70	483	1.4×10^7 (NF)	65	449	1.2×10^7 NF
80	552	2.6×10^7 (NF)	67.5	466	1.3×10^5
90	621	3.7×10^4	70	483	1.2×10^5

Annealed 1950°F (1066°C) for 1 hour and water quenched. NF indicates test was terminated without specimen fracturing. Standard 0.250" (6.4 mm) gage diameter fatigue specimens.

Endurance Limit at 10^7 cycles: 80 ksi (552 MPa) hot rolled condition.
65 ksi (449 MPa) annealed condition.

Applicable Specifications

Note: While this material meets the following specifications, it may be capable of meeting or being manufactured to meet other general and customer-specific specifications.

- ASTM A240
- ASTM A955M
- ASTM A276
- ASTM A479
- ASME SA479
- NACE MR0175
- BS 6744

Forms Manufactured

- Bar-Rounds
- Wire
- Rebar or (Bar-Reinforcing)
- Strip
- Billet
- Wire-Rod

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CARPENTER Specialty Alloys

ALLOY Data

EnduraMet® 316LN Stainless

UNS Number
- S31653

DIN Number
- 1.4429

Type Analysis

Carbon (Maximum)	0.03 %	Manganese (Maximum)	2.00 %
Phosphorus (Maximum)	0.045 %	Sulfur (Maximum)	0.030 %
Silicon (Maximum)	1.00 %	Chromium	16.00 to 18.00 %
Nickel	10.00 to 14.00 %	Molybdenum	2.00 to 3.00 %
Iron	Balance	Nitrogen	0.10 to 0.16 %

Description

EnduraMet® 316LN stainless is a nitrogen-strengthened version of Type 316L stainless. By means of solid solution strengthening, the nitrogen provides significantly higher yield and tensile strength as annealed than Type 316L without adversely affecting ductility, corrosion resistance or non-magnetic properties. In the hot rolled unannealed condition, yield strengths of 75 ksi (518 MPa)or higher can be achieved for bar diameters up to 1.375in (34.925 mm).

Applications

Rebar has been a primary application for EnduraMet 316LN stainless. Specific rebar applications have included bridge decks, barrier and retaining walls, anchoring systems, chemical plant infrastructure, coastal piers and wharves, bridge parapets, sidewalks, and bridge pilings. Because of its low magnetic permeability, EnduraMet 316LN has been used in concrete rebar applications in close proximity to sensitive electronic devices and magnetic resonance medical equipment. The higher strength capability, 75 ksi (518 MPa) minimum yield strength, of EnduraMet 316LN is an added economical advantage.

Scaling

EnduraMet 316LN stainless has excellent scale resistance up to 1600°F (871°C).

Corrosion Resistance

In general, the corrosion resistance of EnduraMet 316LN stainless is similar to Type 316L. The higher nitrogen content enhances chloride pitting and crevice corrosion resistance.

EnduraMet 316LN withstands not only ordinary rusting but also most of the organic and inorganic chemicals. It resists corrosion by nitric acid and sulfurous acid compounds.

EnduraMet 316LN has good intergranular corrosion in the as-annealed and as-welded conditions due to its low carbon content. Some intergranular attack may occur in the hot rolled unannealed condition.

For optimum corrosion resistance, surfaces must be free of scale, lubricants, foreign particles, and coatings applied for drawing and heading. After fabrication of parts, cleaning and/or passivation should be considered.

Physical Properties continued

Important Note: *The following 5-level rating scale is intended for comparative purposes only. Corrosion testing is recommended; factors which affect corrosion resistance include temperature, concentration, pH, impurities, aeration, velocity, crevices, deposits, metallurgical condition, stress, surface finish and dissimilar metal contact.*

Nitric Acid	Good	Sulfuric Acid	Moderate
Phosphoric Acid	Moderate	Acetic Acid	Good
Sodium Hydroxide	Moderate	Salt Spray (NaCl)	Good
Sea Water	Moderate	Sour Oil/Gas	Moderate
Humidity	Excellent		

Physical Properties

Specific Gravity

As Rolled	7.90	
Annealed	7.91	

Density

As Rolled	0.2850 lb/in^3	7900 Kg/m^3
Annealed	0.2860 lb/in^3	7910 Kg/m^3

Mean Coefficient of Thermal Expansion – EnduraMet 316LN Stainless
0.5" (12.5 mm) diameter rebar

Test Temperature		Hot Rolled Condition		Annealed Condition	
77°F to	25°C to	10-6/°F	10-6/°C	10-6/°F	10-6/°C
122	50	7.90	14.22	9.32	16.77
212	100	8.76	15.76	9.23	16.62
302	150	9.11	16.39	9.29	16.73
392	200	9.32	16.78	9.46	17.03
482	250	9.48	17.06	9.52	17.24
572	300	9.62	17.31	9.69	17.44
662	350	9.72	17.50	9.78	17.61
752	400	9.84	17.72	9.87	17.77
842	450	9.96	17.92	9.96	17.93
932	500	10.06	18.11	10.04	18.07
1012	550	10.15	18.27	10.11	18.19
1112	600	10.31	18.55	10.19	18.34
1202	650	10.42	18.75	10.30	18.54
1292	700	10.53	18.96	10.38	18.68

Annealed 1950°F (1066°C) for 1 hour and water quenched. Dilatometer specimens were .250" (6.4 mm) sq. x 2" (50.8 mm) long.

Heat Treatment

Annealing
Heat to 1850/2050°F (1010/1121°C) and rapidly quench in water or air. Typical hardness is Rockwell B 90/95.

Hardening
Cannot be hardened by heat treatment.

Workability

Hot rolling and controlling the finishing temperature can strengthen EnduraMet 316LN bar. After hot rolling, bars are not annealed.

Workability continued

Hot Working
EnduraMet 316LN stainless hot works similar to Type 316L, except more power is required to produce the same reduction.

Heat uniformly to 2100/2300°F (1149/1260°C). Reheat as often as necessary. Cool forgings in air. For optimum corrosion resistance, forgings must be annealed.

Cold Working
EnduraMet 316LN can be heavily cold worked without intermediate annealing. Because of its higher initial strength, more power is required than Type 316L. Cold working can significantly increase strength and hardness.

Machinability
The machinability of EnduraMet 316LN is similar to other nitrogen-strengthened stainless steels, like EnduraMet 18Cr-3Ni-12Mn. Slow to moderate speeds, moderate feeds and rigid tools should be considered. Chips lend to be tough and stringy. Chip curlers or breakers are helpful. Use a sulfurized cutting fluid, preferably of the chlorinated type.

Following are typical feeds and speeds for EnduraMet 316LN stainless.

Typical Machining Speeds and Feeds – EnduraMet 316LN Stainless
The speeds and feeds in the following charts are conservative recommendations for initial setup. Higher speeds and feeds may be attainable depending on machining environment.

Turning—Single-Point and Box Tools

Depth of Cut (Inches)	High Speed Tools			Carbide Tools (Inserts)			
	Tool Material	Speed (fpm)	Feed (ipr)	Tool Material	Speed (fpm) Uncoated	Speed (fpm) Coated	Feed (ipr)
.150	M2	60	.015	C6	250	300	.015
.025	T15	70	.007	C7	300	350	.007

Turning—Cut-Off and Form Tools

Tool Material		Speed (fpm)	Feed (ipr)						
			Cut-Off Tool Width (Inches)			Form Tool Width (Inches)			
High Speed Tools	Carbide Tools		1/16	1/8	1/4	1/2	1	1½	2
T15		45	.001	.001	.0015	.0015	.001	.0007	.0007
	C6	160	.004	.0055	.0045	.004	.003	.002	.002

Rough Reaming

High Speed		Carbide Tools		Feed (ipr) Reamer Diameter (inches)					
Tool Material	Speed (fpm)	Tool Material	Speed (fpm)	1/8	1/4	1/2	1	1½	2
M7	60	C2	80	.003	.005	.008	.012	.015	.018

Drilling

High Speed Tools									
Tool Material	Speed (fpm)	Feed (inches per revolution) Nominal Hole Diameter (inches)							
		1/16	1/8	1/4	1/2	3/4	1	1½	2
T15, M42	45-55	.001	.002	.004	.007	.010	.012	.015	.018

Workability continued

Die Threading

FPM for High Speed Tools				
Tool Material	7 or less, tpi	8 to 15, tpi	16 to 24, tpi	25 and up, tpi
T15, M42	4-8	6-10	8-12	10-15

Milling, End-Peripheral

Depth of Cut (inches)	High Speed Tools						Carbide Tools					
	Tool Material	Speed (fpm)	Feed (ipt) Cutter Diameter (in)				Tool Material	Speed (fpm)	Feed (ipt) Cutter Diameter (in)			
			1/4	1/2	3/4	1-2			1/4	1/2	3/4	1-2
.050	M2, M7	65	.001	.002	.003	.004	C2	245	.001	.002	.003	.005

Tapping

High Speed Tools	
Tool Material	Speed (fpm)
M1, M7, M10	12-25

Broaching

High Speed Tools		
Tool Material	Speed (fpm)	Chip Load (ipt)
M2, M7	10	.003

When using carbide tools, surface speed feet/minute (SFPM) can be increased between 2 and 3 times over the high-speed suggestions. Feeds can be increased between 50% and 100%.

Figures used for all metal removal operations covered are average. On certain work, the nature of the part may require adjustment of speeds and feeds. Each job has to be developed for best production results with optimum tool life. Speeds or feeds should be increased or decreased in small steps.

Weldability
EnduraMet 316LN stainless can be satisfactorily welded by the shielded and resistance welding processes. Oxyacetylene welding is not recommended, since carbon pickup in the weld may occur. Since austenitic welds do not harden on air cooling, the welds should have good toughness.

When a filler metal is required, consider using a welding consumable with a matching analysis to Type 316LN or AWS E/ER 209. Both should provide welds with strength approaching that of the base metal. If high weld strength is not necessary, then consider AWS E/ER 316L.

Post-weld annealing is not required for most applications, but will provide optimum properties for severe service.

Typical Mechanical Properties

Typical Room Temperature Hot Rolled Mechanical Properties – EnduraMet 316LN Stainless
Samples were full-section rebar

Bar Size		Rebar #	0.2% Yield Strength		Ultimate Tensile Strength		% Elongation in 8” (203 mm)
in	mm		ksi	MPa	ksi	MPa	
0.5	12.7	4	93	642	115	794	27.5
0.75	19.1	6	84	580	113	780	29.0

Typical Mechanical Properties continued

Mechanical Properties at Various Test Temperatures – EnduraMet 316LN Stainless
0.5" (12.5 mm) diameter rebar

	Test Temperature		0.2% Yield Strength		Ultimate Tensile Strength		% Elonga-tion in 4D	% Reduction of Area
	°F	°C	ksi	MPa	ksi	MPa		
As-Rolled	-100	-73	110	756	150	1032	61.5	80.5
Annealed	-100	-73	64	444	130	894	81.0	84.0
As-Rolled	70	21	88	607	118	812	48.4	79.7
Annealed	70	21	46	318	95	657	67.6	81.3
As-Rolled	400	204	63	436	91	629	41.4	74.8
Annealed	400	204	28	195	74	513	50.6	80.9

Annealed 1950°F (1066°C) for 1 hour and water quenched. Standard 0.250" (6.4 mm) gage diameter tensile specimens.

CVN Impact Data at Various Test Temperatures – EnduraMet 316LN Stainless
0.5" (12.5 mm) diameter rebar

Condition	Test Temperature		Charpy V-Notch Impact Strength	
	°F	°C	ft-lbs	Joules
As-Rolled	70	21	94	128
Annealed	70	21	100	136
As-Rolled	32	0	109	148
Annealed	32	0	90	122
As-Rolled	-100	-73	104	141
Annealed	-100	-73	83	113

Annealed 1950°F (1066°C) for 1 hour and water quenched.
Sub-size specimens 0.197" x 0.394" (5 mm x 10 mm) per ASTM E23.

RR Moore Rotating Beam Fatigue Tests – EnduraMet 316LN Stainless
0.5" (12.5 mm) diameter rebar

Hot Rolled Condition			Annealed Condition		
Test Stress		Cycles to Fracture	Test Stress		Cycles to Fracture
ksi	MPa		ksi	MPa	
40	276	1.5×10^7 NF	35	242	2.1×10^7 NF
50	345	2.8×10^7 NF	50	276	1.4×10^7 NF
60	414	1.3×10^7 NF	43	297	1.5×10^7 NF
65	449	2.8×10^7 NF	45	311	1.4×10^7 NF
67.5	466	2.1×10^7 NF	50	345	7×10^3 (bent)
70	483	3.7×10^5	60	466	2×10^3 (bent)

Annealed 1950°F (1066°C) for 1 hour and water quenched. NF indicates test was terminated without specimen fracturing. Standard 0.250" (6.4 mm) gage diameter fatigue specimens.

Endurance Limit at 10^7 cycles: 67.5 ksi (446 MPa) hot rolled condition.
45 ksi (311 MPa) annealed condition.

Applicable Specifications

Note: While this material meets the following specifications, it may be capable of meeting or being manufactured to meet other general and customer-specific specifications.

- ASTM A955
- ASTM A276
- ASTM A240
- ASTM A479
- BS 6744: 2001

Forms Manufactured

- Bar-Rounds
- Billet
- Rebar or (Bar-Reinforcing)
- Strip
- Wire
- Wire-Rod

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Sydney Opera House, ANCON CCL, UK

GENERAL APPLICATIONS

Stainless steel rebar has been used as concrete reinforcement in numerous applications including bridge decks, barrier walls, stanchions, parking garages, sidewalks, retaining walls and marine structures (sea walls, piers, jetties, moorings, etc.). Of paramount importance in the decision to use stainless steel is the required corrosion resistance in the application. The material has also found acceptance in areas where a low magnetic permeability material is required. These include deperming piers, magnetic resonance imaging (MRI) equipment, and electric motor foundations.

Alternative materials such as carbon steel and coated products in harsh environments, whether coastal or due to chloride corrosion from road salts, have inadequate corrosion resistance resulting in increased repair and rehabilitation costs. In these applications, where a long design life and minimum maintenance is required, stainless is an attractive alternative and cost justifiable. Stainless steel has excellent corrosion resistance to chlorides in concrete and numerous studies (both long term and accelerated short term tests) have validated this claim.

GUIDELINES FOR SHIPPING, HANDLING, FABRICATING & PLACEMENT OF STAINLESS STEEL REBAR

GENERAL COMMENTS

Stainless steel rebars are very rugged and durable.To maximize the corrosion-resistant properties of stainless steel, a certain amount of care is required during shipping, handling, fabrication and placement. For example, contact with carbon or low alloy steels can cause iron particles to become embedded in the stainless steel, which may result in surface staining.

Although stainless steels are much more resistant to corrosion than carbon steels, some alloys may suffer surface staining or localized corrosion in certain chloride-containing environments. Hence, stainless steel rebars should be protected from direct contact with chlorides (de-icing salt, calcium chloride, seawater, etc.) prior to embedment in concrete.

Although unlikely at the pH levels encountered in cured concrete, galvanic corrosion may occur on carbon steel when it is connected to stainless steel. To prevent galvanic corrosion from occurring under corrosive conditions, stainless steel rebars should not make metal-to-metal contact with carbon steel rebars or other carbon steel components in the structure. Simply keeping the two metals separated (plastic sleeves, etc.) will eliminate this potential problem.

NOTE: The Ontario Ministry of Transportation undertook a research project at Queen's University to investigate potential negative effects from contact between stainless steel and black steel reinforcement.

Results show that the corrosion rates between the galvanically coupled black steel and stainless steel are so small that distress of the structure is unlikely during the 75-year design life.

As a result of the report, the Ministry will no longer specify isolation between black and stainless steel reinforcement.

SHIPPING & HANDLING

- Prior to shipping, ensure that all chains and steel bands will not come into direct contact with the stainless steel rebars. Wood or other soft materials (thick cardboard) should be placed under the tie-downs. Alternatively, nylon or polypropylene straps should be used to secure the rebars.
- When bundles of carbon steel and stainless steel rebars must be shipped one on top of the other, the stainless steel rebars should be loaded on top. Use wooden spacers to separate the two materials.
- Outside storage of stainless steel rebars is acceptable. Consideration should be given to covering the stainless steel rebars with tarpaulins.
- Stainless steel rebars should be stored off the ground or shop floor on wooden supports. Stainless steel rebars should be stored separately from carbon steel rebars.
- Keep carbon steel tools, chains, slings, etc. off stainless steel rebars.
- Stainless steel rebars that require movement by fork-lift truck should be adequately protected so as not to scratch them or to contaminate the material by direct contact with the forks.
- Do not use carbon steel lifting devices. Use nylon or polypropylene slings.

FABRICATION

- Ensure that the stainless steel rebar is free of mill scale prior to fabrication. If mill scale is present, it should be removed by pickling or abrasive blasting (please consult the rebar supplier).
- If the rebar requires cleaning prior to the start of fabrication, it should be cleaned by a pressurized water spray. Do not use seawater or brackish water. Grime that cannot be removed by water washing should be removed with a non-chlorinated detergent, followed by a pressurized water wash.
- All hand tools should be stainless tools that have not been previously used on carbon steel. Mechanized tools and handling devices (such as shears, rollers, tooling, etc.) may be carbon steel provided they have a minimum hardness of Rockwell C35. Such steel tools and devices are to be wiped down with clean rags and cleaning agents prior to being used for stainless steel rebars.
- In order to avoid surface contamination with carbon steel particles or mill scale, it is recommended that stainless steel rebar should be processed on dedicated equipment.
- Do not use grinding tools or abrasive cut-off discs that have been previously used on carbon steel.
- Any iron pick-up/contamination should also be removed with pickling paste.
- Excessive thermal oxidation (or "blueing") caused by cutting with an abrasive cut-off disc should be removed with pickling paste. Using a cut-off wheel with ample water-cooling will usually avoid this potential problem.
- It will be necessary to apply more force in order to bend stainless steel rebars. Also, they tend to have more "spring" than carbon steel rebars and may need to be overbent, to compensate for this "spring-back."
- Stainless steel rebars must not be "hot" bent or "hot" straightened.
- Stainless steel rebars can be welded together using various welding techniques. Care should be taken to clean any dirt, grease and oil from the edges to be welded. Correct welding rods/electrodes and procedures must be used (please consult the rebar supplier or a knowledgeable welding supply house). After welding, all slag and oxidation should be removed by wire-brushing (with a clean stainless steel brush) or by the application of a proprietary pickling paste.
- To ensure good quality welds and proper post-weld clean-up, any tack-welding or joining of stainless steel rebar is best performed in the fabrication shop, rather than on site.
- Fabricated rebar is often shipped to the job site in "bundles", held together with wire. In the case of stainless steel rebar, the bundling wire should be plastic-coated or should be made of stainless steel. Do not use carbon steel ties.

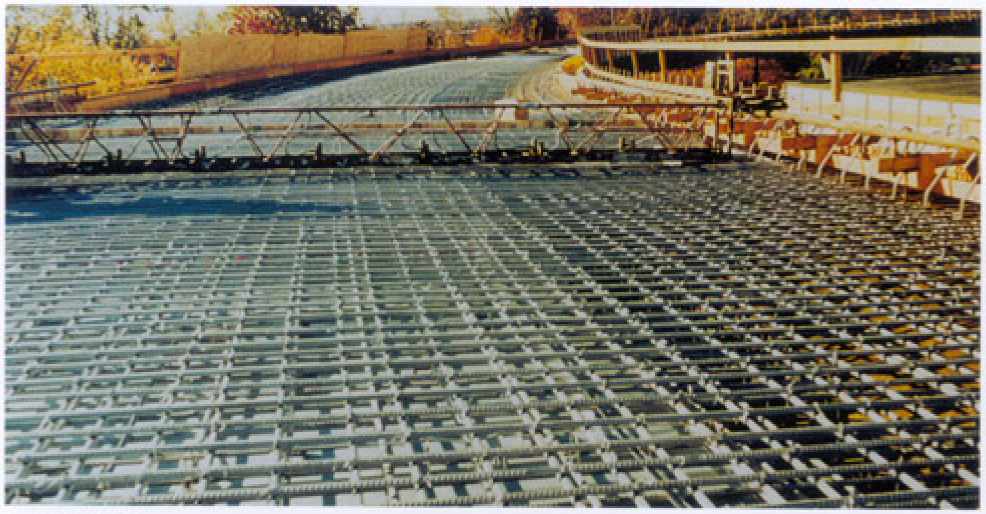
PLACEMENT

- Stainless steel rebars should be supported and spaced using plastic "chairs" and spacers.
- Stainless steel couplers are available for connecting lengths of bar together longitudinally.
- Rebars must be held together with stainless steel tie-wire. Coils of stainless steel tie-wire (3.5 lb) are available to fit the standard, belt-mounted reels.
- To avoid possible galvanic corrosion problems, the tie-wire should have a level of corrosion resistance equivalent to that of the stainless steel rebars being used.
- Fully annealed (fully soft) Type 316 or 316L tie-wire (1.6mm/0.063in. diameter) is usually a good choice for this purpose and will facilitate twisting and cutting.
- At locations in the structure where the ingress of moisture, oxygen and chlorides will be absent, or judged to be extremely low, stainless steel and carbon steel may be connected together. However, to guard against any unforeseen changes in the future, consideration should be given to placing electrical insulation material between the dissimilar metal connections, whenever possible.

Corrosion Service Co., Canada

Frank N. Smith

Frank N. Smith



Acerinox USA, Inc

CLEANING AND PICKLING

Stainless Steels, received in the pickled condition, can usually be easily cleaned with a mild soap and water. In some cases a degreaser may be needed. In cases where rusting, iron contamination or weld oxide must be removed, stainless steel brushes can be employed in localized areas. For more general cleaning, stainless steels are often cleaned with a commercial pickling paste.

GUIDELINES FOR ACCEPTABLE FINISH*

* Per Ontario Ministry of Transportation

NOTE: "B" can exhibit some light discoloration with no impact on service life.

"C" heavy rust

"D" pits and rolled-in-scale

SPECIFICATIONS-STAINLESS STEEL REBAR

ASTM A-955M and British Standard 6744

RELATED STAINLESS SPECIFICATION FOR BAR AND WIRE PRODUCTS

ASTM A-276 Specification for Stainless Steel Bars and Shapes
ASTM A-478 Stainless and Heat Resistant Weaving Wire
ASTM A-493 Stainless and Heat Resistant Wire for Cold Heading and Forging
ASTM A-555 Stainless Steel Wire and Rod — General Requirements
ASTM A-342 Test Methods for Permeability of Feebly Magnetic Materials
ASTM A-564 Specification for Hot Rolled and Cold Finished Stainless Steel Bars and Shapes
ASTM A-484 Specification for General Requirements of Stainless and Heat Resistant Shapes

LITERATURE/BIBLIOGRAPHY MATERIAL ON STAINLESS STEEL REBAR

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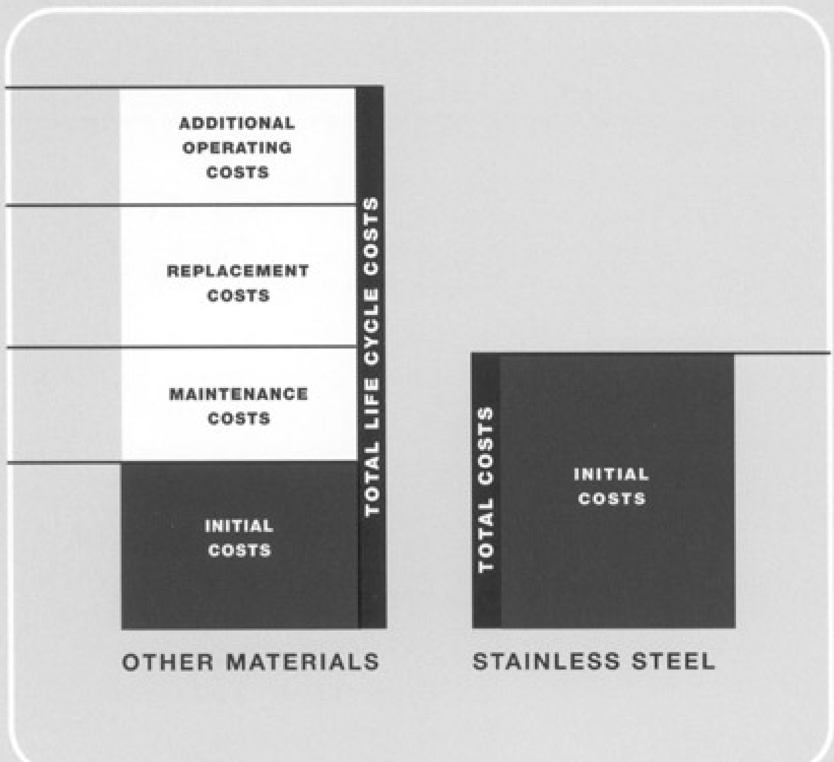
Ontario Ministry of Transportation	Research Agreement No. 9015-A-000045. Some Corrosion Aspects of Stainless Steel Reinforcement in Concrete

Stainless Steel Rebar and related construction products have been in use in the United States and Canada since 1996. Stainless steels have found increasing acceptance as the material of choice where a highly corrosion resistant material is needed to combat the ravages of corrosion from chlorides. The interested reader is advised to explore this publication for information relating to how stainless steel can insure longevity and minimum maintenance in even the harshest of environments. This will not only be cost justifiable, but accrue substantial savings to the owner through the benefits of Life Cycle Costing.



DISCLAIMER

The material presented in this Stainless Steel Rebar Guide has been prepared for the general information of the user and should not be used or relied on for specific applications without first securing competent advice.

The authors and owners of this guide do not represent or warrant its suitability for any general or specific use and assume no liability or responsibility of any kind in connection with the information herein.

ACKNOWLEDGMENTS

Some of the information contained in this brochure was provided by F.N. Smith.

WHY STAINLESS STEELS

Upgrading to more corrosion resistant construction materials like stainless steel is one cost effective approach to the rust problem. Compared to other construction materials, stainless steels have many unique properties that are advantageous not only from a corrosion standpoint, but from a strength and safety viewpoint as well.

Stainless steels are fire and heat resistant, impact and shock loading resistant, can withstand deformation, and require little or no maintenance. Stainless steel's ease of fabrication, installation, weldability and ductility make it an ideal material for many construction applications.

LIFE CYCLE COSTING ADVANTAGES

Life cycle costing techniques and analysis allow the design engineer and materials specifier to consider the true cost of a project over its useful life. Using upgraded, more costly materials at the very start of a project oftentimes can be justified by pointing to the savings accrued over the project's life. Reduced maintenance, inspection and repair and replacement costs result from using upgraded material.

Technical Datasheet

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Unit Display: English

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BioDur® CCM Plus® Alloy

Identification

U.S. Patent Number

- 5,462,575

Type Analysis

Carbon	0.20 to 0.30 %	**Chromium**	26.00 to 30.00 %
Molybdenum	5.00 to 7.00 %	**Cobalt**	Balance
Nitrogen	0.15 to 0.20 %		

General Information

Description

BioDur® CCM Plus® alloy is a non-magnetic, cobalt-chromium-molybdenum alloy exhibiting high strength, corrosion resistance, and wear resistance.

This alloy is a high carbon version of BioDur Carpenter CCM® alloy and meets the requirements of ASTM F1537, ASTM F799, ISO 5832-12 and ISO 5832-4.

BioDur CCM Plus alloy is a wrought powder metallurgy product produced by vacuum induction melting (VIM) followed by gas atomization and hot isostatic pressing to produce 100% dense billets. These billets are then processed by conventional steel-making practices to produce finished products.

BioDur CCM Plus alloy possesses the following product attributes:

* homogeneous chemistry and microstructure;

* small, uniformly distributed carbides, typically less than 10 microns in length as measured on longitudinal sections;

* fine austenitic grain size, typically ASTM E112 grain size number 12 and finer for hot rolled material and 10-11 and finer for material annealed at 2050/2100°F (1121/1149°C) for 1 hour and water quenched;

* improved forgeability over BioDur Carpenter CCM alloy;

* meets ASTM F799 requirements without requiring thermomechanical processing;

* retains a high strength level after high temperature annealing;

* improved machinability over BioDur Carpenter CCM alloy.

Because BioDur CCM Plus alloy does not require thermomechanical processing in order to meet ASTM F799 mechanical property requirements, Carpenter normally supplies the finished product in the hot worked condition.

Applications

BioDur CCM Plus alloy should be considered as a candidate for use in the orthopedic industry for joint replacement and fracture fixation devices such as total hip, knee, and shoulder replacements, especially when wear or fatigue properties are of major importance or where intricate high strength forgings are required.

BioDur CCM Plus alloy should be considered for use in producing large forgings where it is difficult to attain ASTM F799 properties throughout the forging's cross section due to a lack of sufficient thermomechanical processing. Applications have included hip and knee forgings and machined modular femoral heads for metal-metal and metal-HDPE wear couples.

Corrosion Resistance

Important Note: *The following 4-level rating scale is intended for comparative purposes only. Corrosion testing is recommended; factors which affect corrosion resistance include temperature, concentration, pH, impurities, aeration, velocity, crevices, deposits, metallurgical condition, stress, surface finish and dissimilar metal contact.*

Nitric Acid	Excellent	Sulfuric Acid	Good
Phosphoric Acid	Good	Acetic Acid	Excellent
Sodium Hydroxide	Moderate	Salt Spray (NaCl)	Excellent
Sea Water	Good	Humidity	Excellent

Properties

Physical Properties

Specific Gravity	
--	8.28
Density	
--	0.2990 lb/in³
Mean Specific Heat	
73°F	0.1080 Btu/lb/°F
212°F	0.1120 Btu/lb/°F
572°F	0.1230 Btu/lb/°F
1112°F	0.1410 Btu/lb/°F
1652°F	0.1550 Btu/lb/°F
1832°F	0.1570 Btu/lb/°F
2012°F	0.1610 Btu/lb/°F
Poisson's Ratio	
--	0.300
Modulus of Elasticity (E)	
--	35.0 x 10^3 ksi
Modulus of Rigidity (G)	
--	13.4 x 10^3 ksi

Typical Mechanical Properties

Typical Mechanical Properties—BioDur Carpenter CCM Alloy
The following data are provided for comparison to BioDur CCM Plus Alloy.

Condition	0.2% Yield Strength		Ultimate Tensile Strength		% Elongation in 4D	% Reduction of Area	HRC Hardness
	ksi	MPa	ksi	MPa			
Annealed	85	585	150	1035	25	23	30
Warm Worked	135	930	190	1310	26	23	40
Hot Worked	110	760	160	1100	25	23	33

Typical Mechanical Properties—BioDur CCM Plus Alloy
Tensile specimens were low stress ground prior to testing.

Condition		0.2% Yield Strength		Ultimate Tensile Strength		% Elongation in 4D	% Reduction of Area	HRC Hardness
		ksi	MPa	ksi	MPa			
Hot Worked		135	930	198	1365	22	17	43
Annealed	2000°F/1hr+WQ	128	882	196	1351	22	18	42
	2050°F/1hr+WQ	123	848	203	1399	28	24	41
	2100°F/1hr+WQ	117	806	202	1392	29	25	40
	2200°F/2hr+WQ	104	717	190	1310	32	27	36
ASTM F799 Requirements		120	827	170	1172	12	12	35

Workability

Hot Working

BioDur CCM Plus alloy should be hot worked from a furnace temperature of 2050/2100°F (1121/1149°C). BioDur CCM Plus alloy produces a forging that meets ASTM F799 requirements without using thermomechanical processing.

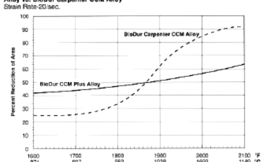
Gleeble Testing for Hot Workability

Gleeble* testing is used by Carpenter Technology as a measure of a material's hot workability. On-heating Gleeble data show the general temperature range over which an alloy can be hot worked at a given strain rate, as well as the temperature where the ductility falls to zero (hot shortness).

The temperature corresponding to the peak ductility of the on-heating curve is recommended to be used as the heating temperature for the material, see the figure entitled "Comparative On-Heating Gleeble Curves." Using this temperature, the Gleeble on-cooling curve is generated, see the figure entitled "Comparative On-Cooling Gleeble Curves." This curve shows relative ductility as a function of temperature and reduction of area. Forty to fifty percent reduction of area is considered acceptable. Fifty to sixty percent is good, sixty to seventy percent is excellent and higher than seventy percent is superior.

*Gleeble is a registered trademark of Dynamic Systems Inc.

Comparative On-Cooling Gleeble Curves from 2100°F (1149°C)—BioDur CCM Plus Alloy vs. BioDur Carpenter CCM Alloy
Strain Rate-20/sec.



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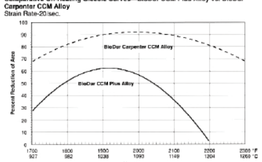

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- **Alloy name search**—Type a partial alloy name or number, such as 304, to see all data sheets that contain that text string
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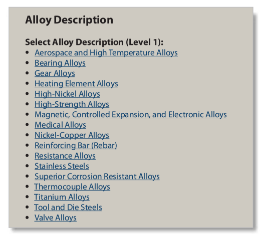
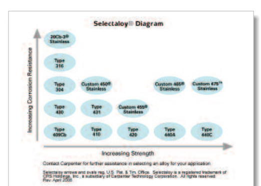
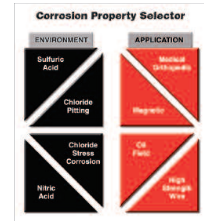


Save time searching for the right alloy. Register for free to use these interactive search tools and time-saving features:

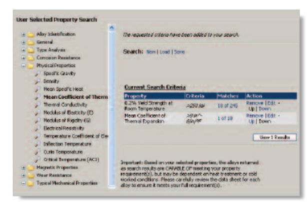
- **Selectaloy® diagram**—Use Carpenter's patented Selectaloy system to find the right stainless alloy based on its corrosion resistance-to-strength ratio



- **Magnetic property selector**—Use this selection matrix to compare classes of Carpenter soft magnetic alloys based on sensitivity, strength and cost
- **Corrosion property selector**—This interactive tool helps you find the alloys that have been used in severely corrosive environments



- **Tooling material selector**—Choose the right matched tool and die steel for your application by comparing wear resistance, toughness, hardening accuracy/safety and red hardness
- **Keyword search**—Use this drilldown menu of pre-defined terms and properties to find the alloy(s) you need
- **Typical properties search**—Lets you enter a range of data for up to 11 alloy properties
- **Selected properties search**—More advanced than the typical properties search, you can customize, edit and save searches using dozens of alloy properties



- **My Materials**—Create your own customizable lists of materials for quick reference

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- Alloy category
- Selectaloy® diagram
- Magnetic property selector
- Corrosion property selector
- Tooling material selector
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- Typical properties search
- Selected properties search
- Technical articles
- My materials

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