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 grades:

EnduraMet™ 32	EnduraMet 316LN
EnduraMet 2205	EndruaMet 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 #16 (9.5 mm through 50 mm)
- Capable of meeting ASTM 955 and BS 6744

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 8% 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 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

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

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

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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

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CARPENTER

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® 2304 Stainless

UNS Number

- S32304

DIN Number

1.4362

Type Analysis

Single figures are nominal except where noted.

Carbon (Maximum)	0.03%	Manganese (Maximum)	2.50%
Phosphorus (Maximum)	0.040%	Sulfur (Maximum)	0.030%
Silicon (Maximum)	1.00%	Chromium	21.50 to 24.50%
Nickel	3.00 to 5.50%	Molybdenum	0.05 to 0.6%
Nitrogen	0.05 to 0.20%	Iron	Balance

Description

EnduraMet® 2304 stainless is a lean duplex stainless steel that has a microstructure consisting of austenite and ferrite phases. This duplex microstructure and the chemical composition of EnduraMet 2304 stainless results in an excellent combination of strength and corrosion resistance.

EnduraMet 2304 stainless has twice the annealed yield strength of typical austenitic stainless steels, like Type 304. 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. (34.925 mm).

EnduraMet 2304 stainless possesses good resistance to general corrosion in many acid environments, chloride stress corrosion cracking, pitting and crevice corrosion.

Applications

Rebar has been a primary application for EnduraMet 2304 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. The higher strength capability, 75 ksi (518 MPa) minimum yield strength of EnduraMet 2304 stainless rebar is an added economical advantage. Other applications for EnduraMet 2304 stainless have included bridge tie wire and dowels.

Corrosion Resistance

Compared to conventional austenitic stainless steels, like Type 304, EnduraMet 2304 stainless has good resistance in most oxidizing and reducing acids; chloride pitting and crevice corrosion resistance due to higher chromium, molybdenum and nitrogen content; and resistance to chloride stress corrosion cracking due to its duplex microstructure.

EnduraMet 2304 stainless has good intergranular corrosion resistance 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.

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	Good	Sour Oil/Gas	Moderate
Humidity	Excellent		

Physical Properties

Specific Gravity	7.77	
Density	0.281 lb/in^3	7770 Kg/m^3

Magnetic Properties

In the annealed and hot rolled conditions, EnduraMet 2304 stainless is ferromagnetic.

Heat Treatment

Annealing
Heat to 1900/2000°F (1038/1093°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.

Hot rolling and controlling the finishing temperature can strengthen EnduraMet 2304 stainless bar. After hot rolling, bars are not annealed.

Workability

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 2304 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 2304 stainless. The data listed should be used as a guide for initial machine setup only.

Typical Machining Speeds and Feeds – EnduraMet® 2304 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

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) 1/4	1/2	3/4	1-2	Tool Material	Speed (fpm)	Feed (ipt) Cutter Diameter (in) 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

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 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 2304 stainless has been welded using many of the standard electric arc welding processes. Autogeneous welding will increase the amount of ferrite present in the weldment 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® 2304 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	86.5	597	121.0	835	25.0
0.625	15.9	5	92.0	635	117.0	807	27.0
0.750	19.1	6	88.0	607	115.0	794	30.0
1.00	25.4	8	96.5	666	120.0	828	29.0

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

Forms Manufactured

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

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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		Speed (fpm)	Feed (ipr)						
			Cut-Off Tool Width (Inches)			Form Tool Width (Inches)			
Micro-Melt® Powder HS Tools	Carbide Tools		1/16	1/8	1/4	1/2	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						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	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

CARPENTER
Specialty Alloys

ALLOY Data

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		% Elongation 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.

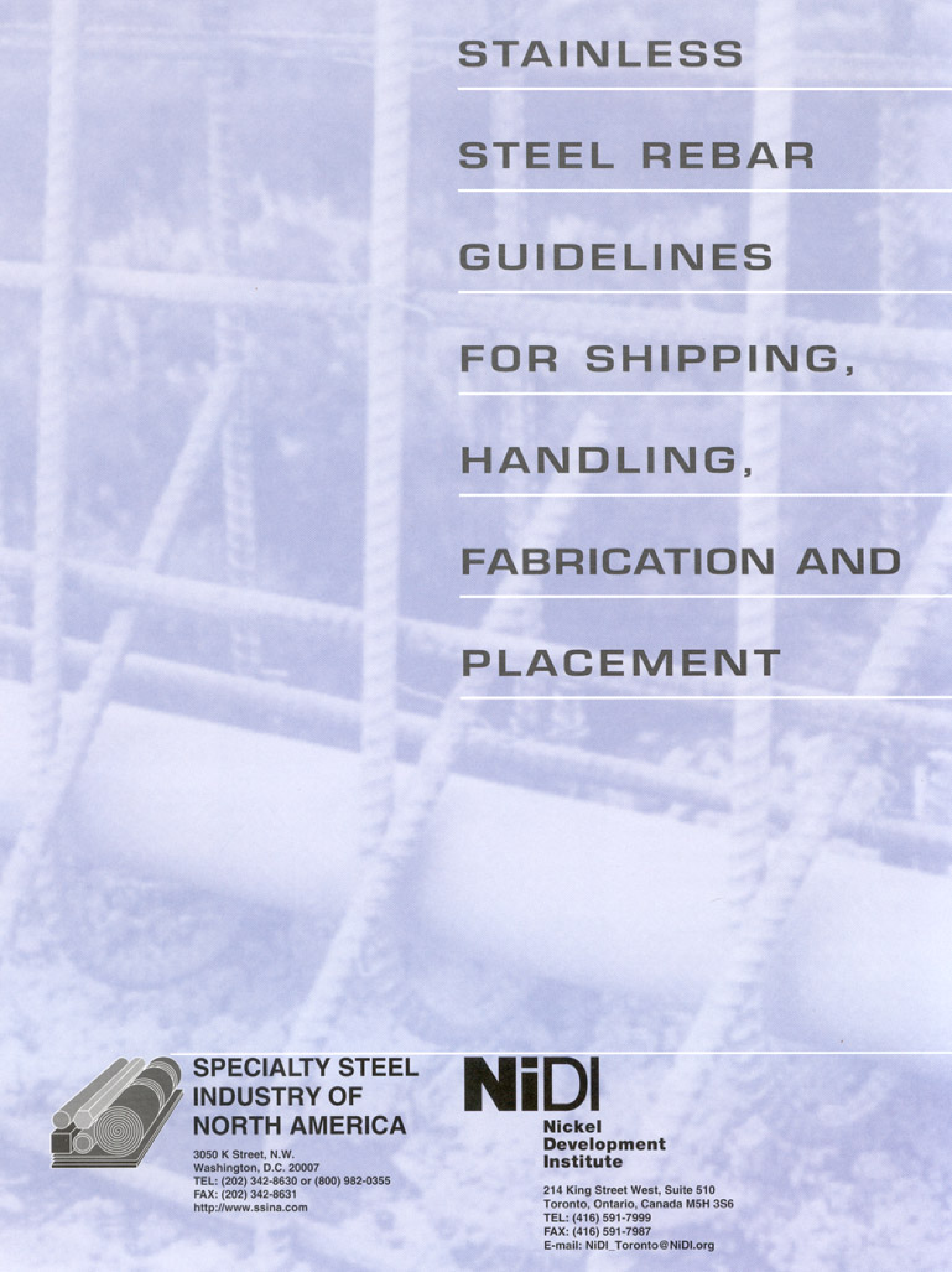
Applicable Specifications

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



STAINLESS STEEL REBAR GUIDELINES FOR SHIPPING, HANDLING, FABRICATION AND PLACEMENT

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Washington, D.C. 20007
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FAX: (202) 342-8631
http://www.ssina.com

NiDI

Nickel Development Institute

214 King Street West, Suite 510
Toronto, Ontario, Canada M5H 3S6
TEL: (416) 591-7999
FAX: (416) 591-7987
E-mail: NiDI_Toronto@NiDI.org

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.

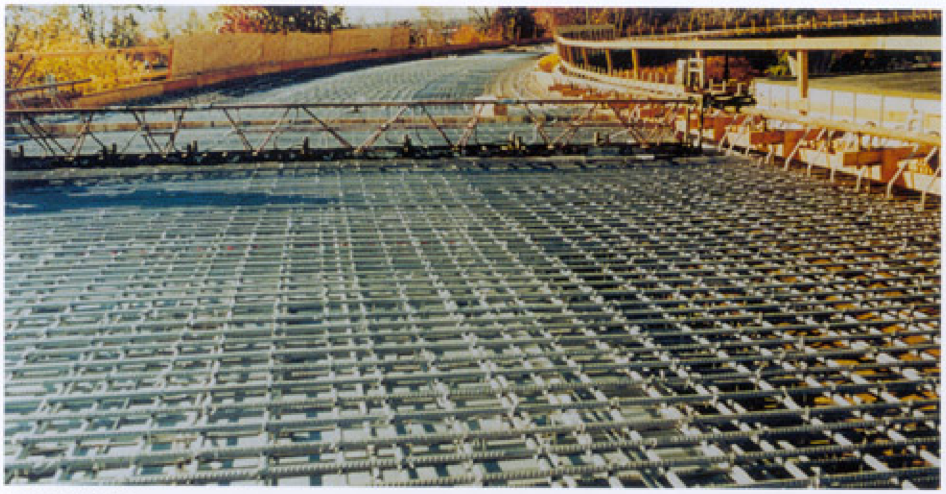
PLACEMENT

- 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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Pastore, Pedeferri	Electro-Chemical Studies on the Use of Duplex Steel In Concrete
Pastore, Pedeferri	Corrosion Behavior of a Duplex Stainless Steel in Chloride Contaminated Concrete
Neuhart	Use of Stainless Steels in Reinforced Concrete - Status 1998
Rasheeduzzafar	Performance of Corrosion Resistant Steels in Chloride Bearing Concrete
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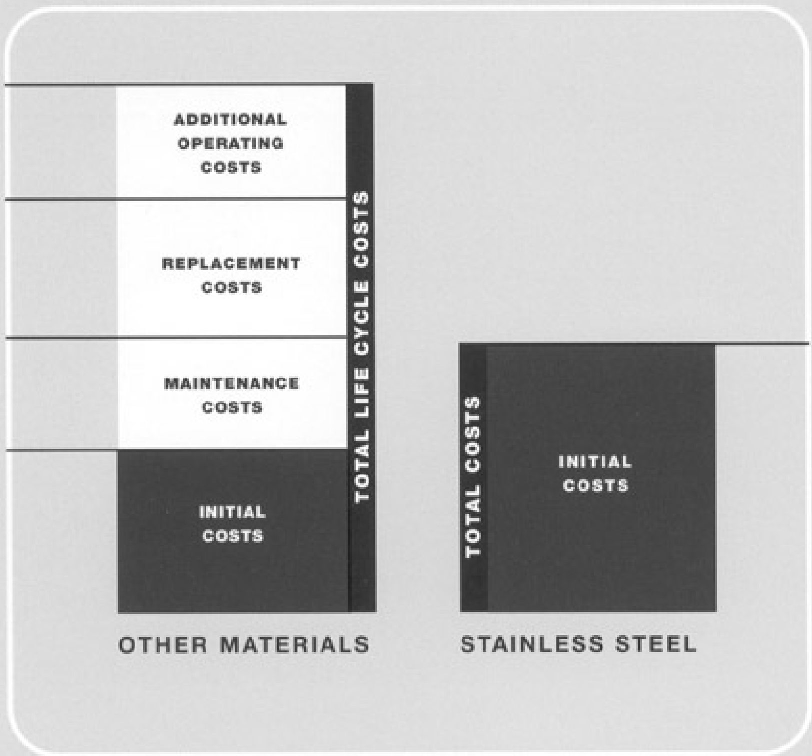
McDonald, Pfeiffer, Sherman	Corrosion Evaluation of Epoxy-Coated, Metallic-Clad and Solid Metallic Reinforcing Bars in Concrete. Federal Highway Administration Report No. FHWA-RD-98-153
Ontario Ministry of Transportation	Research Agreement No. 9015-A-000045. Some Corrosion Aspects of Stainless Steel 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.



ACKNOWLEDGMENTS

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

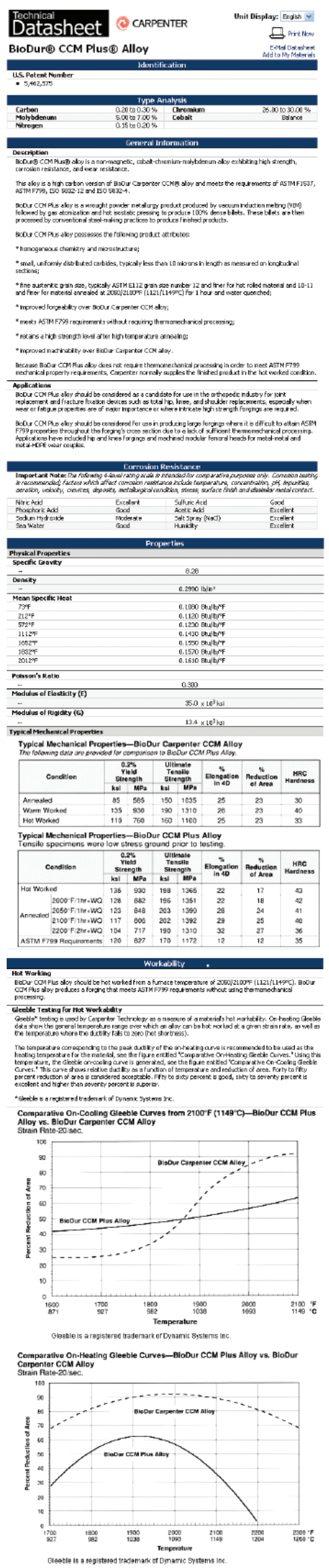
WHY STAINLESS STEELS

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 CARPENTER

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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)	
--	35.0×10^3 ksi
Modulus of Rigidity (G)	
--	13.4×10^3 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		136	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.

Gleeble is a registered trademark of Dynamic Systems Inc.

Comparative On-Heating Gleeble Curves—BioDur CCM Plus Alloy vs. BioDur Carpenter CCM Alloy

Strain Rate-20/sec.

Gleeble is a registered trademark of Dynamic Systems Inc.

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- Learn about forging, passivating and machining alloys in the Technical Reference section
- View or print conversion tables for hardness, decimal equivalents and more
- View a glossary of metals industry terms and a Carpenter mill tour video in the Materials 101 section
- Get answers to specific technical questions from Carpenter metallurgists in our Blog
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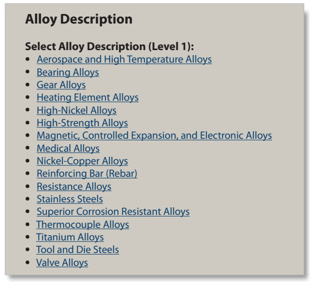
- **Alloy name search**—Type a partial alloy name or number, such as 304, to see all data sheets that contain that text string
- **Alloy description**—Use this drilldown menu to find alloys by features, metalworking properties or possible applications



Alloy Description

Select Alloy Description (Level 1):
- Aerospace and High Temperature Alloys
- Bearing Alloys
- Gear Alloys
- Heating Element Alloys
- High-Nickel Alloys
- High-Strength Alloys
- Magnetic, Controlled Expansion, and Electronic Alloys
- Medical Alloys
- Nickel-Copper Alloys
- Reinforcing Bar (Rebar)
- Resistance Alloys
- Stainless Steels
- Superior Corrosion Resistant Alloys
- Thermocouple Alloys
- Titanium Alloys
- Tool and Die Steels
- Valve Alloys

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

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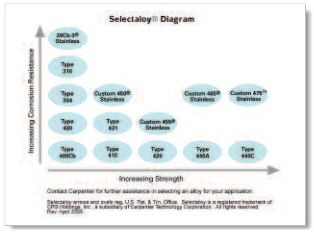

- **Magnetic property selector**—Use this selection matrix to compare classes of Carpenter soft magnetic alloys based on sensitivity, strength and cost
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- **Tooling material selector**—Choose the right matched tool and die steel for your application by comparing wear resistance, toughness, hardening accuracy/safety and red hardness
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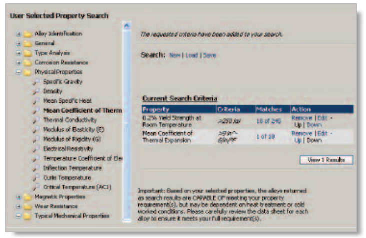
- **Typical properties search**—Lets you enter a range of data for up to 11 alloy properties
- **Selected properties search**—More advanced than the typical properties search, you can customize, edit and save searches using dozens of alloy properties



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- Magnetic property selector
- Corrosion property selector
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- Technical articles
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