ENGINEERING
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Technical Note

Frequently Asked Questions (FAQ) About Stainless Steel Reinforcing Bars

Introduction

CRSI routinely receives inquiries concerning various aspects of reinforcing bars, and reinforced concrete design and construction. This *Technical Note* presents a collection of typical questions that are asked regarding stainless steel reinforcing bars. Most of these questions come from licensed design professionals (LDPs), namely engineers and architects, field personnel (inspectors, code enforcement personnel, and contractors), and state Departments of Transportation (DOTs).

Stainless steel reinforcing bars are experiencing increased use in reinforced concrete projects because of the material's inherent properties, which depending upon the chemistry specified, may include corrosion resistance, low magnetic permeability, ductility, or a combination thereof. Figure 1 shows one example of the increased use of stainless steel reinforcing bars on a bridge deck in Minnesota. But what classifies steel as a stainless steel, as opposed to carbon steel? Stainless steel is defined by ASTM A941 (ASTM 2018b) as steel conforming to a specification that requires, by mass percent, a minimum chromium (Cr) content of 10.5 percent, and a maximum carbon (C) content of 1.20 percent. The carbon content of stainless steel reinforcing bars is less than 0.15 percent as indicated in Tables 1A and 1B. As presented herein, there are several stainless steel alloys used for reinforcing bars. The specific alloy used depends on the project requirements and design properties required by the LDP.

Specific frequently asked questions (FAQ) and responses are provided below.

Basic Material Characteristics

What Standards govern stainless steel reinforcing bars? Stainless steel reinforcing bars should be specified according to ASTM A955/A955M, (ASTM 2018c). ASTM A276/A276M (ASTM 2017), is another standard for stainless steel which is the reference for the chemistry requirements of A955/A955M.

Figure 1 – Stainless steel reinforcing bar used in the deck of a bridge structure located in Minnesota.

What alloys of stainless steel do the ASTM standards permit as reinforcing bars? ASTM A955/A955M states that the "chemical composition of the stainless steel alloy shall be selected for suitability to the application involved by agreement between the manufacturer and the purchaser. This is an important consideration in achieving the desired corrosion resistance or controlled magnetic permeability or both, because these properties are not provided by all stainless steels".

The chemical composition of the alloy must conform to the requirements of Table 1 in ASTM A276/A276M. Each alloy is identified by the six-character Unified Numbering System (UNS) designation starting with the letter "S" followed by five numeric digits. Specifications should always include the UNS number because it indicates the specific chemistry requirement(s). In addition, when recognized by ASTM A276/A276M, the common generic name or AISI type designation for the stainless steel alloy is noted in the second column. ASTM A955/A955M provides guidance regarding alloys commonly used for concrete reinforcement, but this is not a complete list of the products that could meet the requirements of the standard.

Stainless steels are classified by their microstructure into families: austenitic, ferritic, martensitic, or duplex. Only austenitic or duplex stainless steels are produced to requirements of ASTM A955/A955M

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reinforcing steel. All austenitic stainless steels are primarily composed of chromium and nickel while manganese is sometimes substituted for some of the nickel to reduce alloy cost. These steels are identified as S20000 series or "200" series. The traditional nickel alloys are identified as the S30000 or "300" series. Duplex stainless steels are dual-phase alloys with an approximate 50 – 50 austenite and ferrite combination.

Tables 1A and 1B provide the UNS numbers, the common or AISI Type names included in ASTM A276/A276M, and the primary alloying additions for the most commonly used austenitic and duplex stainless steel reinforcing bars and dowels. Stainless steels are low carbon iron based alloys. Their corrosion resistance is determined by their chromium, molybdenum, nickel and/or nitrogen content. Nitrogen also increases strength. All stainless steel families include alloys with different levels of corrosion resistance.

The typical austenitic stainless steels in Table 1A, known commonly as XM-28 and 316LN are used as reinforcing bars because they provide an excellent combination of corrosion resistance in concrete, strength, and ductility. Austenitic stainless steels are essentially nonmagnetic as well, unless altered by cold working.

The typical duplex stainless steels, known as 2205 and 2304 in Table 1A are magnetic and provide higher strength than austenitic stainless steels.

The four alloys presented in Table 1A are the most corrosion resistant stainless steel reinforcement alloys commonly used in the market at the time this document was published.

Table 1A –Typical stainless steel reinforcing bar alloys and their primary alloying elements [1]

UNS Designation	Type or Common Name	Composition %						
		Carbon (C)	Manganese (Mn)	Chromium (Cr)	Nickel (Ni)	Molybdenum (Mo)	Nitrogen (N)	Other Elements
Austenitic								
S24100	XM-28	0.15	11.00 - 14.00	16.50 - 19.00	0.50 - 2.50	-	0.20 - 0.45	
S31653	316LN	0.03	2.00	16.00 - 18.00	10.00 - 13.00	2.00 - 3.00	0.10 - 0.16	
Duplex (Austenitic - Ferritic)								
S31803	2205	0.03	2.00	21.00 - 23.00	4.50 - 6.50	2.50 - 3.50	0.08 - 0.20	
S32304	2304	0.03	2.50	21.50 - 24.50	3.00 - 5.50	0.05 - 0.60	0.05 - 0.20	Cu: 0.05 - 0.60

(1) ASTM A276/A276M determines chemistry requirements. All alloys are iron-based and have additional residual element maximums.

Table 1B – Typical stainless steel dowel bar alloys and their primary alloying elements [1] [2]

UNS Designation	Type or Common Name	Composition %						
		Carbon (C)	Manganese (Mn)	Chromium (Cr)	Nickel (Ni)	Molybdenum (Mo)	Nitrogen (N)	Other Elements
Austenitic								
S24100	XM-28	0.15	11.00 - 14.00	16.50 - 19.00	0.50 - 2.50	-	0.20 - 0.45	-
S30400	304	0.08	2.00	18.00 - 20.00	8.00 - 11.00	-	-	-
S30403	304L	0.03	2.00	18.00 - 20.00	8.00 - 12.00	-	-	-
S31600	316	0.08	2.00	16.00 - 18.00	10.00 - 14.00	2.00 - 3.00	-	-
S31603	316L	0.03	2.00	16.00 - 18.00	10.00 - 14.00	2.00 - 3.00	-	-
S31653	316LN	0.03	2.00	16.00 - 18.00	10.00 - 13.00	2.00 - 3.00	0.10 - 0.16	-
Duplex (Austenitic - Ferritic)								
S31803	2205	0.03	2.00	21.00 - 23.00	4.50 - 6.50	2.50 - 3.50	0.08 - 0.20	-
S32304	2304	0.03	2.50	21.50 - 24.50	3.00 - 5.50	0.05 - 0.60	0.05 - 0.20	Cu: 0.05 - 0.60

(1) ASTM A276/A276M determines chemistry requirements. All alloys are iron-based and have additional residual element maximums
(2) The dowel bars may be plain or deformed bars.

Austenitic stainless steels 304/304L, XM-28, 316LN and 316/316L and duplex stainless steels 2205 and 2304 presented in Table 1B are used as plain and deformed dowel bar applications.

What alloys of stainless steel are presently available as reinforcing bars? All of the austenitic and duplex stainless steel alloys in Table 1A are available as reinforcing bars in the United States. Specifiers should list all of the acceptable alloy options in project specifications. Specifiers may list all of the acceptable alloys for a project though the least cost alloys prevailing during the bid process will generally be quoted. The austenitic and duplex alloys in Table 1B are typically used for dowel bars available in plain and deformed reinforcement.

What is meant by the term "lean duplex" and how is it applicable to reinforcing bar? Nickel and molybdenum can be expensive elements, and manufacturers have developed duplex stainless steels with less quantity, or "leaner" amounts of these elements to produce more price stable and economical products. The 2205 Duplex (UNS S31803) alloy was fairly common, though its corrosion resistive properties may be greater than what is needed for reinforcing bars embedded in concrete. As such, "lean" duplex stainless steels containing different combinations of alloying elements than those contained in 2205 have been developed and have become fairly common. The 2304 Duplex alloy (UNS S32304) is one example, where the chromium content is slightly higher (23 percent), but the nickel content is reduced (4 percent).

What is stainless steel-clad reinforcement? Stainless steel-clad reinforcement consists of a thin layer of stainless steel over a carbon steel substrate, such as traditional ASTM A615/A615M (ASTM 2018a) or ASTM A706/A706M (ASTM 2016) carbon steel reinforcing bar. The premise of a stainless steel-clad bar is that it offers greater corrosion resistance than a conventional carbon steel bar and it is more economical than a solid stainless steel bar. The cladding is metallic and it is intended to be more resistant to construction site damage than a nonmetallic coating. Special end treatments are required on exposed bar ends to maintain corrosion resistance.

As of the publication date of this technical note, there are currently no producers of stainless steel-clad reinforcement from either North America or from foreign sources. As such, the supply is very limited and there are limitations in the bar sizes available.

What are the available sizes of stainless steel reinforcing bars? Stainless steel reinforcing bars are available in all of the U.S. conventional bar sizes and the metric sizes used in Canada. U.S. bar sizes are #3 through #11, #14, and #18. Metric sizes in Canada are 10M, 15M, 20M, 25M, 30M, 35M, 45M, and 55M. Table 2 provides a list of imperial bar sizes available.

What are the yield and tensile strengths of stainless steel reinforcing bars? Stainless steel reinforcing bars are available in Grade 60 (420) and Grade 75 (520). The minimum yield (f_y) and tensile (f_{ut}) strengths are 60 ksi (420 MPa) and 90 ksi (620 MPa) for Grade 60 (420), and 75 ksi (520 MPa) and 100 ksi (690 MPa) for Grade 75 (520), respectively.

How are stainless steel reinforcing bars marked? Are they the same as the carbon steel reinforcing bar designations? Markings on stainless steel reinforcing bars indicate point of origin, size designation (Arabic number corresponding to bar designation number), type of steel (the letters "SS" or "CR" indicate production to ASTM A955/A955M) and minimum yield strength (one dot for Grade 60 (420) and two dots for Grade 75 (520)). The marking system is the same as for carbon steel bar designations, but the use of two letters or numbers for "type of steel" instead of one and the use of dots rather than lines for minimum yield strength are different.

How can the type of stainless steel be identified? The type of stainless steel is provided on the mill certification, as well as on bar tags. In the field, the type may be identified using a portable X-ray fluorescence (XRF) apparatus.

Do stainless steel reinforcing bars have the same deformation patterns as conventional carbon steel bars? Yes. The predominant stainless steel reinforcing deformation pattern in use in North America is as defined in ASTM A955/A955M which provides for a two-sided deformation pattern similar to that for conventional carbon steel bars outlined in ASTM A615/A615M.

Do stainless steel reinforcing bars have the same weight per foot as conventional carbon reinforcing steel bars? There is a slight difference in the specific gravity and, therefore, in the weight per foot between stainless steel reinforcing bars and carbon steel reinforcing bars. Austenitic stainless steel weight per foot is slightly higher than carbon steel for all the bars shown in Table 2 while the weight per foot for duplex steels relative to carbon varies bar to bar. For both the austenitic and duplex bars, the difference in weight relative to carbon bars is on average more pronounced for smaller bars (sizes #3 to #7) than bars larger than #7. Table 2 contains the weight per foot for A615/A615M, and A955/A955M duplex and austenitic stainless steel reinforcing steel bars by size according to the respective ASTM specifications.

What are the thermal properties of stainless steel reinforcing bars? Stainless steel reinforcing bars generally have a coefficient of thermal expansion slightly higher than that of carbon steel reinforcing bars. The coefficient of thermal expansion is in the range of 7 to 10 x 10^{-6} in./in./°F (17 to 19 x 10^{-6} in./in./°C), depending on the alloy.

Table 2 - Nominal weight per foot of reinforcing bars per ASTM

Bar Size	A615	400 Series; Duplex Alloys	300 Series
	Nominal Weight per Foot (lb/ft)		
#3	0.376	0.374	0.378
#4	0.668	0.679	0.686
#5	1.043	1.048	1.058
#6	1.502	1.495	1.511
#7	2.044	2.038	2.059
#8	2.670	2.685	2.713
#9	3.400	3.396	3.441
#10	4.303	4.312	4.358
#11	5.313	5.296	5.352
#14	7.65	7.64	7.72
#18	13.60	13.59	13.72

What does a typical stress-strain curve for stainless steel reinforcing bars look like? Stainless steel alloys exhibit a "roundhouse" curve when stress versus strain is plotted. This means the yield point of the stress-strain curve is less well-defined than with stress-strain curves for conventional steels, where a well-defined yield plateau is exhibited. However, this effect is less pronounced than in high-strength, carbon steels. The yield is calculated by the 0.2% offset method.

How is the stainless steel reinforcing bar available? The imperial bar sizes available are listed in Table 2. Sizes #3 to #6 are typically produced by the mills in coil and shipped to the fabricator for processing. Bar sizes #7 to #11 are produced by the mills both in coil and as straight bar lengths for shipment to the fabricator for processing.

Compared to straight bar lengths, coils are economical because of process efficiencies at the mill. Coiled bar can reduce waste, as the fabricated bars are made to precise lengths. Coiled bar allows the fabricator to provide continuous bar lengths (up to 60 ft. (18.3 m) in length is typical).

Straight bar lengths are generally made to 40 feet (12.2 m), but longer lengths up to 50 feet (15.2 m) are available upon request.

Engineering Design Issues

Into what fabricated shapes can stainless steel reinforcing bars be bent? Stainless steel reinforcing bars can be fabricated into the entire array of standard bend shapes found in the CRSI *Manual of Standard Practice* (CRSI 2018). The bars are bent using the same pin diameters and to the same dimension diameters as conventional carbon steel reinforcing bars.

Are there any special design guidelines for stainless steel reinforcing bars in ACI 318 or AASHTO? Presently, ACI 318 (ACI 2014) and AASHTO Bridge Design Specifications (AASHTO 2014) generally treat stainless steel reinforcing bars the same as carbon steel reinforcing bars in terms of structural design. The appropriate yield strength will have to be used in the design computations. Design codes treat the development lengths and lap lengths for stainless steel the same as for carbon steel reinforcing bars.

For earthquake-resistant designs, ACI 318 references "tests and analytical studies" are required for use and AASHTO limits the use of stainless steel to seismic design category (SDC) A or in members where plastic hinging is not expected.

Is it better to lap splice or mechanically couple stainless steel reinforcing bars? It depends on many factors and this will likely become an economic decision. For the smaller bar sizes, the "extra" length of stainless steel bar to facilitate the splice requirements will likely be more economical than the selected coupler. For the larger bar sizes, the coupler becomes more economical than the "extra" length of bar used to make the lap splice.

A mechanical coupler may, however, be a better alternative given job specific constructability conditions, congestion issues, and/or spacing requirements. ACI 318 or AASHTO provisions may also influence this decision.

What types of stainless steel mechanical couplers are available? Mechanical couplers are commercially available in stainless steel in standard size threaded couplers. Other types (e.g., transition sizes, terminators, etc.) are available with adequate lead time and order quantity either from the fabricator, manufacturer or distributor. As with any coupler, test data should be utilized to determine suitability of available products.

With respect to mechanical couplers, should the stainless steel alloy match the alloy of the coupled reinforcing bars? Not necessarily. The coupler manufacturers have come to the conclusion that it is not economical to produce and inventory couplers in all of the various alloys. Stainless steel couplers are generally available in the UNS S31803 duplex, which is compatible with all of the reinforcing bar alloys.

Are there any issues to using couplers with stainless steel bars? There are no known issues.

Can stainless steel reinforcing bars be mixed with other reinforcing steel bars? Stainless steel reinforcing bars can be used in structures with other steel reinforcing bars. There has been research on combining stainless and carbon steel concrete reinforcement, for example, in new construction and repairs. It has been determined that galvanic corrosion is not a significant concern, as there is less galvanic interaction between stainless steel and the passive (not corroding) carbon steel, than there is between active (corroding) and passive carbon steel. For more information on this subject, the LDP can refer to the referenced research (Qian et al. 2005).

The LDP should assess whether galvanic corrosion is a concern and establish if insulators such as non-conductive sleeves are necessary.

When is it desirable to use non-magnetic stainless steel alloys? Non-magnetic alloys are necessary in structures where magnetic neutrality is needed, such as hospitals and medical facilities with MRI equipment, deperming piers for maintenance of metal naval vessels, and toll booth stations with open road tolling facilities (e.g., those utilizing *E-ZPass®* or *I-Pass®*). In these structures, duplex alloys should be avoided.

Can the concrete cover distance to stainless steel reinforcing bars be reduced? In some reported instances, LDPs were able to reduce the top and bottom cover over stainless steel reinforcement, for a total reduction of 1 to 2 in. (25 to 50 mm). This equates to a 12.5 to 25 psf (600 to 1200 Pa) reduction in dead load of the concrete deck. Some LDPs design for a cover reduction with the use of stainless steel reinforcing. Before making a change in deck thickness, local bridge or building code provisions should be reviewed for acceptance of this type of change.

Do all stainless steels have the same resistance to corrosion? No, the stainless steel alloys produced to the requirements of ASTM A955/A955M provide varying levels of corrosion resistance due to their different chemical composition. This standard includes corrosion resistance measurement tests which can be used to determine the corrosion resistance of the various stainless steel alloys. The severity of the service environment, expected chloride exposure, and service life should be considered when specifying appropriate alloys. Various accepted corrosion test methods are available to assess the relative resistance of the different types of reinforcing steel to chloride exposure (Nadelman et al. 2016). Such methods can be used to determine the relative ranking of the stainless steel alloy options available. The LDP can also consult publicly available research performed by various entities.

What impact does the use of stainless steel reinforcing have on the life cycle cost of structures subject to corrosion? The use of stainless steel reinforcing bars in such cases has the effect of dramatically reducing repair and maintenance costs over the life cycle of a structure by both significantly delaying the timing of the repair and reducing the severity of the work. The result is an increase in durability, service life and consequently a reduction in life cycle cost.

Construction Issues

How many stainless steel reinforcing bar producers are there in the United States? Does the "Buy America" act apply? As of the publication date of this technical note, there are three domestic steel mills that can manufacture stainless steel reinforcing bar to "Buy America" requirements. The "Buy America" act applies to government projects such as Federally-funded bridge projects, GSA buildings, Corps of Engineers projects, etc. Additional government requirements exist for the use of patented/proprietary products.

Do I need to use stainless steel accessories (e.g., supports, ties, etc.) if I am using stainless steel reinforcing bar? Yes, stainless steel chairs and tie wire are preferred when using stainless steel reinforcing bars. Both are available. Plastic and/or composite chairs can also be used. Also, PVC coated tie wire and nylon "zip" ties can be used at the discretion of the LDP.

Are there any special fabrication and handling requirements? The CRSI *Product Guide* (CRSI 2013) provides information on the fabrication, handling and storage of stainless steel reinforcing bar. This publication is available for download at the CRSI website referenced herein.

Stainless steel should be kept separate from other ferrous metals (i.e. carbon steel) from the point of pickling to placement of the concrete, to prevent cross contamination.

Fabrication of stainless steel reinforcing bars uses the same process as for carbon reinforcing steel bars. However, the contact surfaces of equipment used to fabricate or handle stainless steel bars should not have been previously used for carbon steel, low alloy steel, low carbon chromium steel, or other non-stainless ferritic materials. Ideally, fabrication equipment should be dedicated to the fabrication of stainless steel reinforcing bars, unless adequate cleaning or contamination isolation procedures are in use. Machinery used in fabrication should be protected from carbon contamination. Any friction, contact or pressure point that is exposed in the process of fabrication and/or material handling should be either stainless, carbon steel hardened to a minimum of 34 Rockwell C, or be of a non-corrosive synthetic material.

Synthetic web slings should be used to lift bundles, as opposed to regular chains. Bundling wire should be plastic coated or stainless steel.

What is the availability of stainless steel reinforcing bar? What are the lead times necessary to order and get the bar fabricated? Stainless steel reinforcing bar is available through several domestic and foreign steel mills, and domestic fabricators who keep in inventory the common types and sizes of stainless steel reinforcing bar. Lead times to order and receive fabricated bar is the same as for other steel bar fabricators. In the case of large, multi-year projects, purchasers are encouraged to inquire with a local fabricator about lead times for specific stainless steel alloy types, sizes, and quantities early in the project schedule.

What is the cost of stainless steel reinforcing bar compared with conventional carbon steel bar or other corrosion resistant bars on the market? As a trade organization, CRSI does not comment on costs. Specific manufacturers or suppliers should be contacted for current pricing information.

Are there any storage issues on the project site with the use of stainless steel reinforcing bar? Stainless steel should be stored separately from carbon steel to prevent contamination from mill scale and other ferrous materials. Stored bars should be elevated off the ground on timber dunnage.

Finish Quality

What do I do if I have any discoloration on the bars which appears to be rust staining? The appearance of discolored bars or rust staining is an extremely rare event. However, if after a period of time in your yard or on the construction site you have any concerns relating to discolored bars or apparent rust staining, the fabricator or the mill who supplied the material should be contacted to determine if there is a corrosion or contamination problem, the possible cause and the determination of a solution to be implemented going forward. This issue will be resolved by compliance with the ANSI/CRSI - IPG 4.1 (CRSI 2016).

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Note: References listed above were used in the development of this document. Because these documents are updated on a frequent basis, the year has generally been omitted in the text for clarity. The LDP is referred to the respective organization for the latest revisions and applicable year of adoption.

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Historical: "Frequently Asked Questions (FAQ) About Stainless Steel Reinforcing Bars", Technical Note ETN-M-2-12.

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