Stainless Steel Reinforcement for Concrete Construction

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ABSTRACT

Stainless steel reinforcing bar (rebar) is finding increased application in important concrete structures for which long-term resistance to chloride-containing environments is required. The oldest known structure with stainless steel rebar is a pier in Yucatan, Mexico. Completed in 1941, this pier is still in good condition after 60+ years of exposure to a tropical marine environment. During the last 20-30 years, stainless steel rebar has been widely used in new construction and repair of bridges, parking garages, sea walls, marine facilities and tunnels. This paper discusses the properties and benefits of stainless steel rebar and presents examples of its use.

1. INTRODUCTION

Severe corrosion of carbon steel rebars occurs when moisture, oxygen (air) and chlorides in the surrounding concrete interact with the embedded rebar. Moisture and oxygen from the outside environment can migrate to the rebar via pores or cracks in the concrete cover. Chlorides from marine atmospheres can also migrate through cracks or pores. However, in some parts of the world, chlorides may already be present in the as-cast concrete due to their presence in the aggregate, sand and/or mix water used to make the concrete.

Corrosion-resistant stainless steel reinforcing bar (rebar) can greatly reduce the life-cycle costs of important reinforced concrete structures. Stainless steel rebars have been used in the construction of new bridges and in the repair of bridge decks and barrier walls for 20+ years in North America and for a longer time in Europe.

The oldest structure built with stainless steel reinforcement is the Progreso Pier on the Yucatan Peninsular in Mexico which extends 2 km into the Gulf of Mexico. The pier was completed in 1941 and is still in good condition after 60+ years of exposure to a tropical marine environment.

More recently, stainless steel rebar has been used in the repair and construction of parking garages, sea walls, marine facilities and tunnels and for applications requiring non-magnetic rebar.

2. PROPERTIES OF STAINLESS STEEL REBARS

Table 1 gives nominal alloy compositions of stainless steels that have been used for rebar. Alloys that contain molybdenum (Mo) are known to have better corrosion resistance to chlorides which are, of course, present in seawater and road de-icing salt. The Pitting Resistance Equivalence Number (PREN)
indicates the relative resistance of a particular alloy to chloride pitting attack. The higher the PREN value, the more resistant is the alloy.

Table 1 – Chemical Compositions of Stainless Steels Used for Rebar
Nominal compositions (weight %), balance iron.

<table>
<thead>
<tr>
<th>Alloy</th>
<th>UNS</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>C_max</th>
<th>N</th>
<th>PREN*</th>
</tr>
</thead>
<tbody>
<tr>
<td>304</td>
<td>S30400</td>
<td>18</td>
<td>8</td>
<td>-</td>
<td>0.08</td>
<td>-</td>
<td>18</td>
</tr>
<tr>
<td>304L</td>
<td>S30403</td>
<td>18</td>
<td>8</td>
<td>-</td>
<td>0.03</td>
<td>-</td>
<td>18</td>
</tr>
<tr>
<td>316</td>
<td>S31600</td>
<td>17</td>
<td>11</td>
<td>2.5</td>
<td>0.08</td>
<td>-</td>
<td>25</td>
</tr>
<tr>
<td>316LN</td>
<td>S31653</td>
<td>17</td>
<td>11</td>
<td>2.5</td>
<td>0.03</td>
<td>0.13</td>
<td>27</td>
</tr>
<tr>
<td>2205</td>
<td>S32205</td>
<td>22</td>
<td>5</td>
<td>3.0</td>
<td>0.03</td>
<td>0.14</td>
<td>34</td>
</tr>
</tbody>
</table>

*PREN = Pitting Resistance Equivalent Number = %Cr + 3.3x% Mo + 16x%N

Table 2 gives typical mechanical properties of stainless steels. The modulus of elasticity for stainless steel is very similar to that of structural carbon steel. Figure 1 compares the stress-strain curve of a typical Grade 400 carbon steel rebar with curves for stainless steel rebars made of Type 316LN and Alloy 2205. It can be seen that stainless steel rebars possess excellent strength and ductility.

Table 2 – Typical Mechanical Properties for Type 316 and Alloy 2205

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Young’s Modulus kN/mm²</th>
<th>0.2% Proof Stress MPa</th>
<th>Tensile Stress MPa</th>
<th>Elongation %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kN/mm²</td>
<td>x1000 ksi</td>
<td>MPa</td>
<td>ksi</td>
</tr>
<tr>
<td>2205</td>
<td>200</td>
<td>29</td>
<td>510</td>
<td>73.9</td>
</tr>
<tr>
<td>316</td>
<td>200</td>
<td>29</td>
<td>280</td>
<td>40.6</td>
</tr>
</tbody>
</table>

Note: Exact values can differ with material, thickness, thermo-mechanical treatment, etc.

3. THE BENEFITS OF USING STAINLESS STEEL REBARS

The benefits of using stainless steel rebars are summarized below:

- Excellent corrosion resistance --- especially to chlorides
- Durable reinforced concrete structures can be built with low life-cycle costs
- No rebar coatings or claddings are required
- No rebar coatings to crack, chip or deteriorate
- No rebar coating damage to repair.
- No cut ends to coat or cover.
- No cathodic protection is required for the rebar
- No concrete sealers or membranes are required
- No corrosion inhibitors need to be added to the concrete mix
- Concrete cover depth can be reduced
- High-performance concrete is not required
- Stainless rebar has excellent strength, ductility and toughness
• Stainless steel has a Modulus of Elasticity very similar to structural carbon steel
• Stainless steel rebars are easy to cut and bend (3d bends can be easily made)
• Stainless steel rebar is produced in accordance with ASTM Standard A 955.
• Stainless steel tie-wire, threaded rebar couplers and dowels are also available.
• Stainless steel welded-wire mesh is produced according to ASTM A 1022.
• Some stainless steels are non-magnetic (useful for MRI facilities, laboratories, etc.)

4. EXAMPLES OF STAINLESS STEEL REBAR USAGE IN BRIDGES

Although stainless steel rebar has been extensively used in Europe, the first highway bridge deck to be built in North America with stainless steel rebar was completed in 1984 using Type 304 rebar. The rebar alloys of choice for subsequent bridge decks have been the more corrosion resistant Type 316, 316LN and Alloy 2205 (see Table 1).

Table 3 lists a few of the bridges in North America that have stainless steel rebars in their decks and, in many cases, in their barrier walls. The examples cover a broad spectrum from small local bridges to major highway bridges.

Table 3 – A Few Bridge Projects Involving Stainless Steel Rebar

<table>
<thead>
<tr>
<th>Location</th>
<th>Installed</th>
<th>Grade</th>
<th>Tonnage (approx.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michigan I-696, near Detroit</td>
<td>1984</td>
<td>304</td>
<td>33</td>
</tr>
<tr>
<td>Ontario Hwy 407 Bridge</td>
<td>1996</td>
<td>316LN</td>
<td>12</td>
</tr>
<tr>
<td>Ontario Hwy 401 Bridges</td>
<td>1998-9</td>
<td>316LN</td>
<td>150</td>
</tr>
<tr>
<td>Oregon Brush Creek Bridge</td>
<td>1998</td>
<td>316LN</td>
<td>75</td>
</tr>
<tr>
<td>Oregon Smith River Bridge</td>
<td>1998-9</td>
<td>316LN</td>
<td>120</td>
</tr>
<tr>
<td>New Jersey Highway ramp</td>
<td>1998</td>
<td>2205</td>
<td>165</td>
</tr>
<tr>
<td>Oregon Haynes Inlet Bridge</td>
<td>2002-3</td>
<td>2205</td>
<td>~400</td>
</tr>
<tr>
<td>New York French Creek</td>
<td>2003</td>
<td>316LN</td>
<td>17</td>
</tr>
<tr>
<td>New York Jamestown</td>
<td>2004</td>
<td>2205</td>
<td>20</td>
</tr>
<tr>
<td>New York Falconer</td>
<td>2004</td>
<td>2205</td>
<td>40</td>
</tr>
<tr>
<td>New York Belt Parkway Br., Brooklyn</td>
<td>2004-5</td>
<td>2205</td>
<td>200</td>
</tr>
<tr>
<td>New Jersey Driscoll Bridge</td>
<td>2003-5</td>
<td>2205, 316LN</td>
<td>~1300</td>
</tr>
<tr>
<td>Virginia-Maryland Woodrow Wilson Br.</td>
<td>2004-</td>
<td>2205, 316LN</td>
<td>~1100</td>
</tr>
</tbody>
</table>

Figure 2 shows stainless steel rebar been installed in the deck of a smaller road bridge in French Creek, NY. Approximately 17 tons of Type 316LN rebar was used in this bridge. Figure 3 shows an example
of a much larger bridge ---- the new Woodrow Wilson Bridge which carries the Capital Beltway (Interstate 95/495) over the Potomac River and connects Alexandria, VA with Washington, DC. Stainless steel rebar (~1100 tons) was used in the bascule (lifting) part of the bridge.

In addition to bridge decks and barrier walls, stainless steel rebar has been used for highway entrance and exit ramps and, in the form of spirals, for bridge support structures.

5. EXAMPLES OF STAINLESS STEEL REBAR IN PARKING GARAGES

Table 4 gives examples of parking garages where some stainless steel rebar has been used.

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>REBAR ALLOY(S)</th>
<th>STAINLESS REBAR APPROX. TONNAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brighton, MA</td>
<td>304L, 316LN</td>
<td>20</td>
</tr>
<tr>
<td>Boston, MA</td>
<td>304L</td>
<td>9</td>
</tr>
<tr>
<td>Pittsfield, MA</td>
<td>304L, 2205</td>
<td>14</td>
</tr>
<tr>
<td>Middlebury, VT</td>
<td>304L</td>
<td>4</td>
</tr>
<tr>
<td>Hartford, CT</td>
<td>304</td>
<td>12</td>
</tr>
<tr>
<td>Exeter, NH</td>
<td>304, 304L</td>
<td>9</td>
</tr>
<tr>
<td>Albany, NY</td>
<td>304</td>
<td>15</td>
</tr>
<tr>
<td>Albany, NY</td>
<td>304L</td>
<td>14</td>
</tr>
<tr>
<td>Bloomington, IL</td>
<td>304</td>
<td>23</td>
</tr>
</tbody>
</table>

6. OTHER EXAMPLES OF STAINLESS STEEL REBAR USAGE

In addition to road bridges, highway ramps and parking garages, stainless steel rebar can find use in the following:

- Airport bridges and taxiways
- Retaining walls
- Tunnels: entrance structures and tunnel walls
- Road underpasses
- Sea walls and coastal buildings
- Piers, docks and moorings
- Water- and waste water-treatment plants
- Concrete structures in refineries, chemical processing plants and power generating plants
- Concrete structures subjected to very low temperatures (e.g., liquefied gas storage)
- Restoration of historic buildings
- Strengthening of old bridges
- Hospital MRI facilities and laboratories (using non-magnetic rebar, e.g., Type 316LN)
7. ECONOMICS

When comparing the initial **material cost** of rebar, it is no surprise to find that stainless steel will cost more than carbon steel. However, when new concrete structures are required to last many decades with minimum maintenance, two more important costs must be taken into account. They are **life-cycle cost** and **total project cost**.

The use of stainless steel rebar can significantly reduce future maintenance and restoration work and, therefore, reduce the overall life-cycle cost (LCC) of a structure. This concept can be illustrated with reference to the Öland Bridge which connects the Baltic Sea island of Öland to the mainland of Sweden. This bridge was build during 1968-1972 using carbon steel rebar. Severe chloride corrosion of the rebar quickly developed which resulted in extensive repair work that began in 1990. The final phase of this repair work was completed in 2005. The overall cost for inspections, testing and renovation is estimated to be about twice the cost of the original bridge at current prices. Kilworth and Fallon indicated that using stainless steel rebar, at an additional project cost of 8%, would have given the bridge a lifetime of 100 years with minimum maintenance (see Figure 4).

In order to determine the full economic impact, an LCC analysis should include the “disruption costs” caused by future repair or replacement work. Traffic-related costs could include:

- reduced productivity caused by the late delivery of vehicular freight;
- fuel wasted by vehicles stuck in traffic jams
- fuel wasted by vehicles forced to take lengthy detours
- loss of revenues from toll bridges, toll tunnels and harbour facilities
- disruption of local, national and international trade.

For parking garages, repair work to entrance or exit ramps, floors or inter-floor ramps has a very direct effect on reducing daily revenue. Further information on relevant LCC analyses is available in the literature.

When constructing a new highway bridge, stainless steel rebar is substituted for carbon steel rebar only in critical parts of the structure that will experience corrosive conditions. For a recent project in Brooklyn, NY, it was reported that using stainless steel rebar in critical locations increased the total project cost by about 1%. An increase in total project cost of about 3% was reported for twin-span bridges (313 metres long) recently built in Ireland using 169 tonnes of stainless rebar.

8. CONCLUSION

Future maintenance, energy savings and environmental concerns have focused more attention on life-cycle costs during the initial design stage of public structures. This has led to the requirement for strong and long-lasting construction materials, particularly in chloride-containing environments. The combination of properties offered by stainless steels, such as Type 316, 316LN and Alloy 2205, make them excellent choices for concrete reinforcing bar. A growing number of concrete structures in North America, Europe, Australia and the Mid-East have been built or repaired using stainless steel rebar.
9. FURTHER INFORMATION

Further information on stainless steel rebar is available on the following Internet web sites:

www.stainless-rebar.org
www.worldstainless.org (go to: “Animations”. Select: “Stainless steel reinforcing bar”)

10. REFERENCES


**Figure 1** – Stress-Strain Curves for Carbon Steel (Grade 400) and Stainless Steel Rebars (Alloy 2205 and Type 316LN). Test specimens taken from 25mm diameter bars.

**Figure 2** – French Creek Bridge, New York State. Type 316LN rebar being placed in the deck and barrier walls. (Photo: Dunkirk Specialty Steel)
**Figure 3** – New Woodrow Wilson Bridge Carries the Capital Beltway Over the Potomac River between Alexandria, VA and Washington, DC. Stainless steel rebar was used in the bascule part of the bridge.

**Figure 4** – Life-cycle Cost Comparisons for the Öland Bridge in Sweden, Comparing Type 316 Stainless Steel with Carbon Steel Reinforcement, adapted from Kilworth & Fallon⁴. “Total Cost” is given in millions of Pounds Sterling.