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Main Advantages of Steel in Bridges Construction using improved corrosion

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***Abstract*—** The *main cause of the poor condition of bridges is the lack of maintenance since the cost can reach 10% of the project and, in the environment, the use of oil-based paint are dangerous air pollutants. So is necessary is the use of Cor-Ten steel as an alternative material for the development of functionality and economy. The total lifetime cost of a weather-resistant steel bridge can be up to 30% lower than a conventional steel cladding. In most cases, opting as a solution for weather-resistant steel is more cost effective than a coated steel optimized for most internal environments. It is known as structural steel with improved resistance to atmospheric corrosion containing alloys of copper, nickel, chromium and silicon; taking a reddish-brown color and over time, it darkens*

***Keywords*—Cor-Ten Steel, Weathering Steel, Maintenance, Cost reduction, Atmospheric Corrosion**

I. INTRODUCTION

Corrosion is an important instrument of degradation in steel structures that are affected in a wide range of aggressive environments. Direct exposure to moisture and air pollutants causes steel to corrode at rates that depend primarily on exposure conditions and steel characteristics. [1] This is more important in areas where the level of environmental aggressiveness is high. Atmospheric parameters can lead to metal corrosion, which are temperature, humidity, temperature, solar radiation, wind speed and direction, and air pollutants such as chlorides, sulfur dioxide, carbon dioxide, hydrogen sulfide, etc. [2]

Fig 1. - Corrosion of steel beam

A study conducted between 1999 and 2001 shows that a total of $ 276 billion was spent on issues related to corrosion in the commercial, residential and transportation sectors. This cost is approximately 3% of US GDP in 1998 (United States GDP in 1998 was $ 9.09 billion). Corrosion costs in the infrastructure industry to $ 22.6 billion, of which $ 8.3 billion was spent on road bridges.[3]

1.1 COR-TEN STEEL DESCRIPTIONS

These steels defined in the European standard are intended for use in welded, rivets or bolted structures, whose operating temperature is the environment and must have an improved resistance to atmospheric corrosion.[4] These are not intended to be heat treated, except for products that undergo a standardization forming (lamination process in which the final deformation is carried out within a temperature range such that the state of the material is equivalent to that of would be obtained after a normalization treatment and that allows the specified values of the mechanical characteristics to be maintained even after a new normalization treatment). Stress removal annealing is allowed. As said, it is a steel with improved resistance to atmospheric corrosion, which is added resistance elements, tales such as phosphorus (P), copper (Cu), chromium (Cr), nickel (Ni), molybdenum (Mo), etc. to increase the resistance to atmospheric corrosion, forming a layer of oxides that protects the base metal underlying the influence of atmospheric conditions. [5]

Table. 1: Chemical Composition (%)

Steel Grade		C	Si	Mn	P	S	Cu	Ni	Cr
COR-TEN	Cold rolled sheet	0.08	0.65	0.3	0.09	0.02	0.41	0.48	0.85
	Hot rolled Sheet and plate	0.09	0.6	0.37	0.1	0.022	0.37	0.46	0.92

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Fig 3. - Hokkaido Centennial Memorial Tower (1969, 1973, 1977, 1991 y 2010)

1.2 STEEL PROTECTION OXIDE IN TIME

1.2.1 Protective oxide formation

When weather-resistant steel is exposed to the atmosphere, an orange oxide forms during the first wet period. This oxide resembles the oxide in ordinary steel exposed to the atmosphere. In the surface oxidation of Cor-Ten steel, an oxide film impermeable to water and water vapor is created, which prevents the oxidation of the steel and its progress towards the inside of the piece. [6] A large part of iron corrosion products are retained in the oxide that is formed by the reaction of oxygen present in the air along with the soluble ferrous salts that the corrosion reaction produces. However, some soluble corrosion products are not incorporated into the oxide as evidenced by iron oxide stains on concrete pillars subject to water runoff from exposed steel aging. Subsequent wet periods produce additional rust on the weathering of steel and leakage corrosion products.

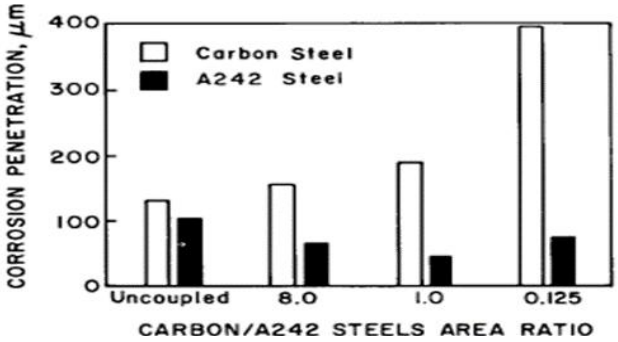

Fig 4. - Corrosion penetration of uncoupled and coupled steels after 6 months in seawater. [Ellis and LaQue, 1951]

Over time, Cor-Ten steel will change to a dark brown, almost purple color. The rate of patina development depends on the degree of exposure to the climate and the presence of pollutants such as chlorides and sulfides in the atmosphere. [7]

1.2.2 Benefits of Cor-Ten steel

Depending on the market price of Cor-Ten steel, it may be higher than carbon steels; however, the cost savings by removing the protective coating system generally outweigh the additional costs of the material. The total lifetime cost of a weather-resistant steel bridge can be up to 30% lower than a conventional steel cladding (El Sarraf and Mandeno, 2010). In most cases, opting as a solution for weather-resistant steel is more cost effective than a coated steel optimized for most internal environments.[8]

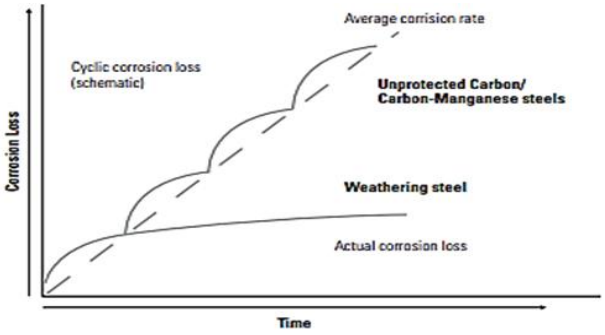

Fig 5. - Schematic comparison between corrosion loss of carbon steels and WS.

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II. DEVELOPING

Weather resistant steels are suitable for use in most locations. However, certain environments may limit the durability of weathering steels. Major problems can occur in environments with constant humidity, an aggressive atmosphere or high levels of air pollution.

1.3 No constant humidity

If left in conditions of permanent humidity or humidity, stainless steel will oxidize like any other unprotected carbon steel. A succession of wet and dry phases is required to form a stable oxide layer on the surface. [9]

1.4 No aggressive atmosphere

High concentrations of chloride ions adversely affect the adhesion of WS. According to EN ISO 9223, weather-resistant steels should not be used within two kilometers of coastal waters unless chloride levels in the air do not exceed the S2 salinity classification (i.e. Cl <300 mg / m2 / day). Direct contact between weather-resistant steels and de-icing salts used on roads should be avoided. [10]

1.5 No atmospheric pollution

Airborne contaminants and industrial fumes can affect patina development. Corrosion is much higher if the metal surface is covered by solid particles such as dust or dirt. These particles can retain moisture and salts. In an industrial atmosphere, large amounts of sulfur dioxide (SO2) [11] are detrimental to the compactness of the patina. EN ISO 9223 advises that weather-resistant steels should not be used without protection in an environment greater than P3 (i.e., SO2> 200 mg / m2 / day).

1.6 Different types and grades of Cor-Ten steel

Table. 2: Physical properties

Weather resistant steel	Standard	Tensile Strength M pa	Yield Strength M pa	Elongation in 2 inches (min.) %
CORTENA	US steel	470-630	355	20
IRSM 41-97	Indian Railways	480 min	340 min	21
ASTM A 588	ASTM	485 M IN	345 min	21

1.7 Different types and grades of Cor-Ten steel

From a practical point of view, an important objective of performing XRD and MS tests was to obtain quantitative data to determine a protective capacity index (EPI) based on oxide mass ratios. In particular, this index would serve to describe the quality (protection) of the WS surface patina. (2006) introduced for the first time a PAI, denoted as α / γ * (where α = cumulative mass ratio of species of protective oxides, and γ * = cumulative mass ratio of species of non-protective oxides), which is defined as: [12]

$$\alpha|\gamma * = \frac{P\alpha}{P\gamma + P\beta + Pm} \quad (1)$$

Fig.6: Iowa Department of Transportation, Page 46

1.8 Process

1.8.1 Oxygen Cut

Weather-resistant steels can be cut with conventional oxygen gas equipment that uses procedures similar to those used in steel structures of the same thickness. As for standard carbon steels, Cor-Ten steels should be preheated between 120 and 150 ° C if:

It is customary to use stages that can be identified with letters as in the example:

- The steel sheets have been stored in a cold environment (< 5°C)
- Edges will undergo high stress or deformation in subsequent processes
- An exact thickness is important

1.8.2 Cold forming – Bending

Weather-resistant steels can be processed with conventional manufacturing methods. A minimum internal radius for bending of 90 ° is recommended, which depends on the thickness of the metal:

Table. 3: Minimum bending radius

Minimum bending radius			
Thickness (mm)	1.3 to 3	3 to 10	10 to 13
Inner radius μ (mm)	1.5	2	3

The radius can be reduced in the direction of flexion. Local surface grinding is recommended before bending. The pressure setting must be adapted to the type of material. A normalization phase may be necessary depending on the level of deformation. [13]

1.8.3 Hot Forming

Hot forming is recommended for:

- Plates over 20mm
- Sheets below 20 mm if the equipment does not have enough power to cold work

1.8.4 Normalising heat treatment

The reheating temperature should be set between 900 and 950°C and followed by air cooling. Annealing to restore the initial mechanical characteristics of the weathering steels is not required.

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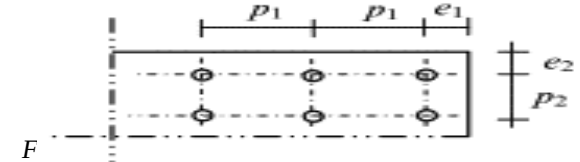
1.8.5 Bolding and Welding Weathering Steel

Welding and screwing are acceptable methods of joining steels for connections. To avoid the excessive development of corrosion, any space must be small enough to prevent oxygen and moisture from reaching the surface. Welding is the best option, since it is easy to perform. Welded joints eliminate spaces where water and moisture can accumulate and create favorable conditions for corrosion.

1.8.5.1 Bolding

Eurocode EN 1993-1-8 provides specific spacing values for bolt holes in weathering steels. If the shape or contour makes it difficult to closely fit nuts and bolts, the joint should be sealed. Alternatively, an anti-corrosive paint should be used on the contact surface. Bolts, nuts, and washers are available in weathering steels. They meet the requirements detailed in ASTM standards A325 and A490 (type 3). Experience shows that stainless steel bolts are also suitable for use with weathering steels. As their mass is negligible, no significant galvanic corrosion occurs. However, galvanized steel should be avoided for bolts and fasteners.



$$e_1, e_2 \leq (3d, 8t_{min}, 125mm) \quad (2)$$

$$e_3, e_4 \leq (6d, 14t_{min}, 175mm) \quad (3)$$

Fig 8.- Accumulation of sediments in the lower string of the truss (Bridge over the Pirris River - National Route 226)

1.8.5.2 Welding

Cor-Ten steel has excellent weldability thanks to its low carbon content and fine grain. It is compatible with all standard welding processes, including submerged arc, armored metal arc, gas metal arc and flux core arc welding. [14] All joints must be continuously welded to avoid moisture and corrosion by local contact.

In pure steel applications, special electrodes should be used if the welds need to reach the required level of (see table 3):

- Strength
- Corrosion resistance
- Weathered appearance (similar to that of the base metal)

$$f_c = \delta_b f_{2b} + \delta_s f_{2s} \quad (4)$$

$$M_c = \delta_b M_{2b} + \delta_s M_{2s} \quad (5)$$

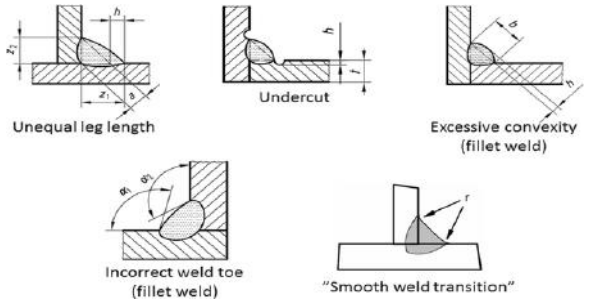


Fig.9: Types of welding

Table IV.- Weldi.ng filler Cor-Ten steel

Proovedor	Referencia	EN ISO	AWS
Esab	OK Autrod 12.51	440 / G3Si1	A5.18 / ER70S-6
	OK AristoRod 13.29	12534 / GMn3Ni1CrMo	A5.28 / ER110S-G
Lincoln Electric	LNM 28	12070 / G465MG3Ni1	A5.28 / ER80S-Gt
	LNM Ni1		A5.28 / ER80S-Ni1t
S. A. F. Air Liquide	Nertalic 70 A	440 / G3Si1	A5.18 / ER70S-6
Thyssen	Union Patinax	440 / G423CGO	A5.18 / ER70S-G

Fig.10.- Comparison of annual loss due to corrosion between carbon steel and Cor-Ten steel

1.9 Testing

Cor-Ten steels offer improved corrosion resistance thanks to the addition of copper during manufacturing. [15] Additional alloy elements can be added to increase the tensile strength of steel or facilitate forming processes. The different alloy elements added to weathering steels influence the properties of steel in the following ways:

- Copper increases the adhesion, compactness and elasticity of Steel
- Phosphorus acts as a catalyst for copper and

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increases the initial reactivity of WS steel by conducting a uniform corrosion distribution without stains, giving the steel a more homogeneous appearance.

- The healing process is accelerated when the oxide layer is accidentally damaged
- Chromium, nickel and silicon increase the mechanical characteristics of the steel substrate.

III. RESULTS

When weather-resistant steel is exposed to the ambient atmosphere, it develops an initial layer of iron oxide in the same way as carbon steel. The oxidation rate depends on how much oxygen, moisture and air pollutants can access the metal surface. In the initial stages, a complex mixture of iron oxides covers the surface to create an oxide layer. As the process progresses, the oxide layer forms a barrier against corrosive agents and decreases the rate of corrosion.

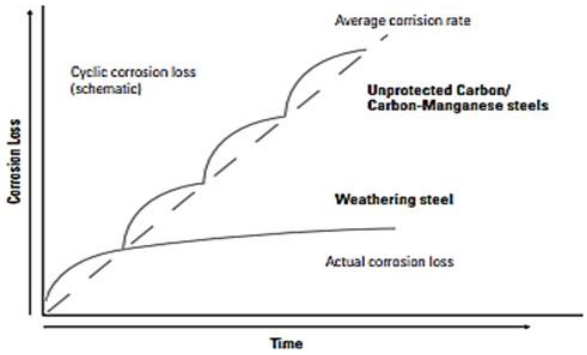

Fig. 11:Schematic comparison between corrosion loss of carbon steels and WS.

In a low alloy carbon steel, the iron oxide layer is porous. Over time, that layer comes off the metal surface and the corrosion process begins again. The oxidation rate progresses in increments that depend on the chemical and mechanical aggressiveness of the environment. It can and with the complete destruction of the metal.

Table captions appear centered above the table in upper and lower case letters. When referring to a table in the text, no abbreviation is used and "Table" is capitalized.

IV. CONCLUSION

Cor-Ten steel is a viable alternative to carbon steels due to the improved corrosion resistance that can reduce the cost of up to 30% than a conventional coating. These steels are suitable for use in most locations. However, certain environments may limit the durability of weathering steels and significant problems may occur in environments: with constant humidity, an aggressive atmosphere or high levels of air pollution.

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