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Study on Mechanical and Corrosion Properties of High Strength EQR Steel Used in Concrete Reinforcement

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Abstract: **The high strength thermo-mechanical structural steel bar of earthquake resistant (EQR) grade was obtained in the form of rod with diameter 16 mm. The specimen for microstructure and tensile tests were prepared as per the ASTM standard. The microstructure of the specimens were obtained using optical metallurgical microscope and revealed that different phase has different microstructure at core and rim of the specimen. The microstructures of all rebar samples comprise an outer tempered martensite ring with an inner core of ferrite-pearlite in between a narrow bainitic transition zone. The mechanical properties of the tensile specimen were obtained using universal tensile machine and the fracture specimen was characterized using scanning electron microscope. The fracture behavior of the EQR steel rebar showed good dependency on microstructures. The hardness of the specimen was obtained at case, core and transition zone of the rebars. The hardness values varied at all the zones due to the variation in microstructures and chemical compositions. The effects of corrosion on the hardness and tensile test results were studied and observed that mechanical properties of the rebar deteriorates as the electrochemical reaction increases due to presence of chloride ions.**

The present work aims to study the evaluation of the microstructure, tensile properties, hardness and corrosion behavior of the various grades of EQR rebars.

Key words: Earthquake resistant (EQR) steel rebar, Corrosion, SEM

I. INTRODUCTION

Steel has been used for many decades in structural applications because of its good combination of mechanical and corrosion resistance properties. In the present scenario many researchers reported that to reduce steel consumption in reinforced cement concrete structures since designers recommend to use high strength steel bars [1]. There are various routes for their production such as microalloying, thermomechanical treatment, cold working, etc. For steel bars of thermomechanical treatment route, some designers believe these steel bars have more strength consequently more sensitive to corrosive environment particularly in acidic environment. Furthermore, the application of high strength steels supported the economics and the elegance of steel as well as reinforced concrete construction. High rise buildings, car park decks, offshore platforms, ocean vessels, bridges, etc. demonstrate the widespread penetration of steel into concrete construction engineering. Most steel used for reinforcement is highly ductile in nature. Its usable strength is its yield strength, as this stress condition initiates such a magnitude of deformation into the plastic yielding range that major causes start to cracking. Structural design engineers are looking for high strength and earthquake resistant steel bars forcing concrete to reduce the overall weight of the structures. To overcome these problems materials scientists have developed various advanced structural steels of proper microstructures through precise control of various thermomechanical treatments and the produced steel called thermomechanically treated earth quake resistance steels.

Since the concrete has very good compressive strength but negligible tensile strength. These types of steels are used for load bearing machine components or other structural applications. In the case of conventional bars, the hot rolled products are cooled naturally in the air so that the microstructures remain fully ferrite pearlite at the center of surface to core. However, these steel bars are forced to cool suddenly by passing them through water chamber just after final rolling so the outer layer of the bar gets quenched with subsequent formation of tempered martensite. Tempered martensite is a very strong phase, which provides high strength and relatively soft ferrite-pearlite structure at core provides necessary ductility of the steel [7]. The thermo mechanical technology of manufacturing steel bars adopts a wide range of mechanical properties in the high strength low alloy steel rebars. The quenching process of surface layer of the bar gives a hard strong wear resistance surface while the soft ferrite-pearlite core renders ductility and toughness. Thus the hardness and corrosion resistance of developed steel bars are better than the conventional steel bars and lot of properties are accommodated. Some major influenced properties are listed below

a) Higher yield strength
b) Improved hardness and wear resistance
c) Higher toughness
d) Good ductility and bendablity
e) Higher resistance to brittle cleavage
f) Higher resistance to low-energy ductile fractures

1.1 Grain size effect on mechanical properties of steel

In a polycrystalline alloy, the grain size or average grain diameter usually influences the mechanical properties. A

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fine-grained material is harder and stronger than one that is coarse-grained material. For many materials, the yield strength, σy, varies with grain size according to the Hall-Patch equation, where d is the average gain diameter, and σ_0 and ky are constant for a particular material.

$\sigma_y = \sigma_0 + k_y d^{-1/2}$

Grain size may be regulated by the rate of solidification from the liquid phase, and also by plastic

deformation followed by an appropriate heat-treatment. In many literatures reported that grain sizereduction not only improves the strength of the material but also enhance the toughness of many alloys.

II. EXPERIMENTAL PROCEDURE

2.1 Metallographic sample preparation

Metallography is a very important process for characterizing any structural engineering material which reveals microstructures of the test samples. In order to reveal the different zones, to measure the depth of the hardened zones, and to know the microstructures, metallography was performed on the TMT steel rebars. For this metallographic samples were cut in cross-section from the stock materials of about 2.5 cm along the length. The faces of cross-sectioned samples were ground in a grinding wheel. Then, these faces were subjected to progressive grinding and with a series of emery papers of different grit size ranging from 80-1000 following the standard procedure. After that, wet polishing was done in rotating cloth wheel at 300 rpm with alumina powder of size 0.05 µm mixed with water. After smooth polishing, the samples were washed in water and dried with acetone. The dried samples were etched using 2% Nital solution (2% HNO3 acid in Ethanol) as etching reagent for these steel rebar to reveal the microstructure.

2.2 Chemical composition by Optical Emission Spectroscopy (OES)

The chemical compositions of the collected thermomechanical treated steel bars of two different types were analyzed by Optical Emission Spectroscopy (OES) technique. For this experiment, two samples from each steel rebars were cut in cross-section from the long length materials of about 2.5 cm along the length. The faces of cross-sectioned samples were firstly ground in a grinding wheel. After that, two faces of each sample were polished with different grades ofemery papers to create smooth flat surface. Two sparks were taken in a face of each rebar and the average results were considered for chemical compositions of the steel bars.

2.3 Hardness

Hardness is one of the important characteristic of selecting good steel for reinforcing into concrete. Hardness like strength defines the resistance against deformation plastically of the material. It is very easy to measure and is a very popular non-destructive test for quality inspection of materials. The hardness of used steel bars has shown greater than the conventional hot rolled bars due to presence of tempered martensite and other strong phases present in its microstructure.

2.4 Corrosion measurement

Corrosion of steel bars in concrete structures is the major cause of failure and it severely reduces the strength and life of structures in humid conditions and presence of chloride environment. These ingredients from atmosphere percolate through the concrete cover and causes deterioration of steel. After initiation of corrosion in reinforcing steel, it expands on the surface as corrosion products and occupies a volume of more times greater. For degradation behavior of these steel, weight loss and electrochemical techniques were used to measure the corrosion behavior of used steel bars in simulated acidic media in laboratory scale. The obtained results were shown in Fig.4 and 5.

III. RESULTS AND DISCUSSION

The obtained microstructure are shown in Fig. 1 (a) and (b) which directly governs and correlates the mechanical properties and performances of materials when it is in service atmosphere.

TABLE 3.1: Chemical composition of alloy in wt%

Alloy	C	Mn	Si	S	P	Cu	Cr	Ni	CE
Steel 1	0.16	0.7	0.14	0.02	0.03	0.24	0.07	0.07	0.33
Steel 2	0.18	0.8	0.20	0.02	0.03	0.18	0.04	0.05	0.35

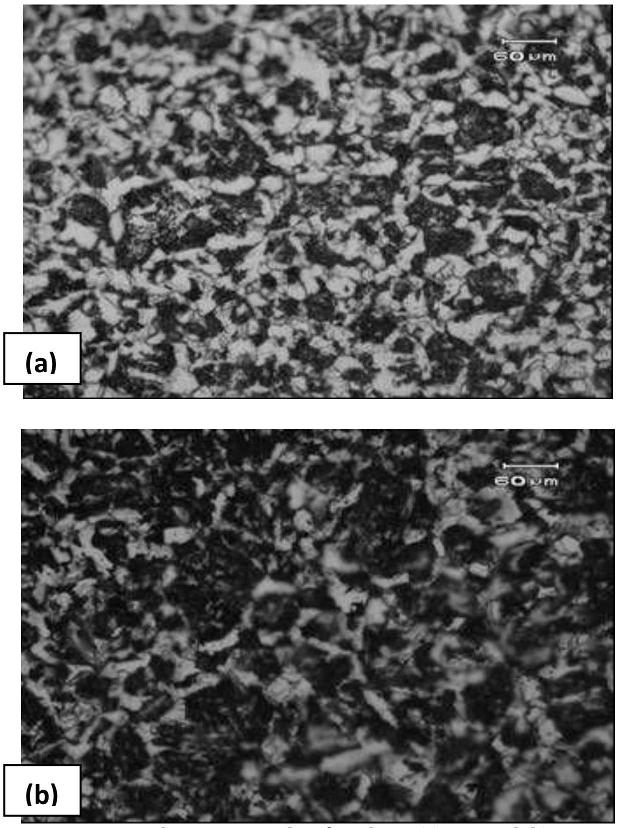

Fig.1: Optical micrographs of steel 1 at (a) core and (b) Rim

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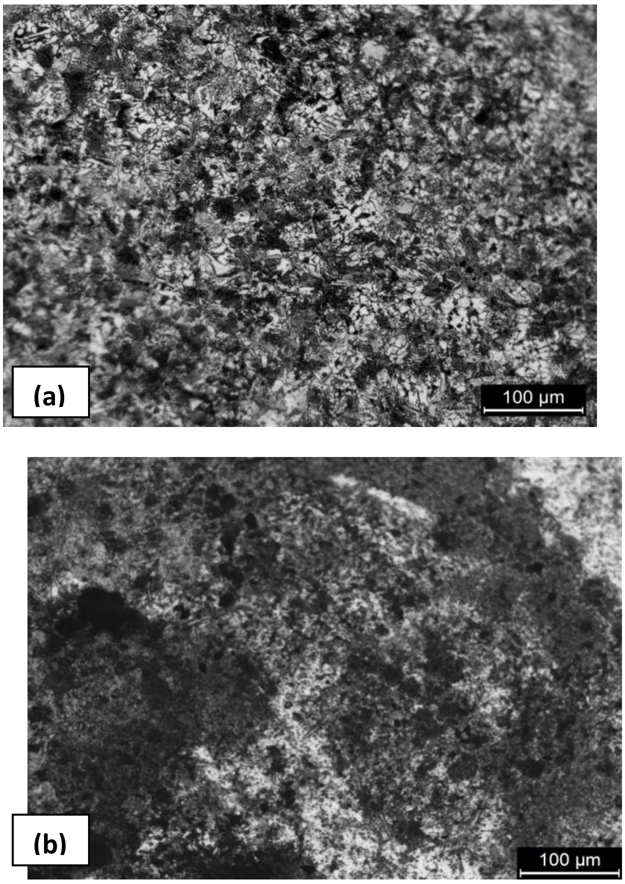

Fig.2: Optical microgrographs of steel 2 at (a) core and (b) Rim

The resultant microstructures (Fig.1&2 a, b) revealed the fine grain structures which indicate its thermomechanical route of production and resulting in greater strength. The alloy steel 1 possessing smaller carbon equivalent value than other specimen and thus shown the comparatively higher strength. Hence through this study, it is observed that the process treatment and microstructure has vital importance to achieve desired properties of degradation as well as mechanical strength.

After 96 hrs of exposure the fractured surface micrographs has been presented at different sections as core, intermediate and rim. It is observed that chemical attack is severe at the outer surface comparison to others.

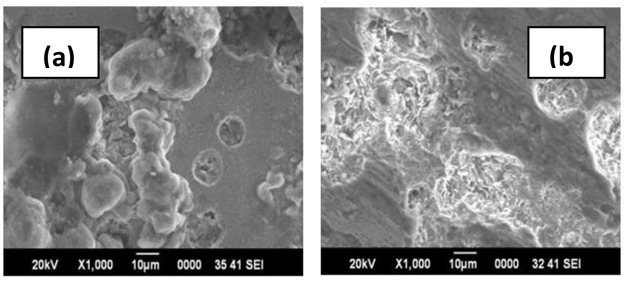

Fig.3: SEM microgrograph of steel 1 at (a) core and (b) Rim after exposure

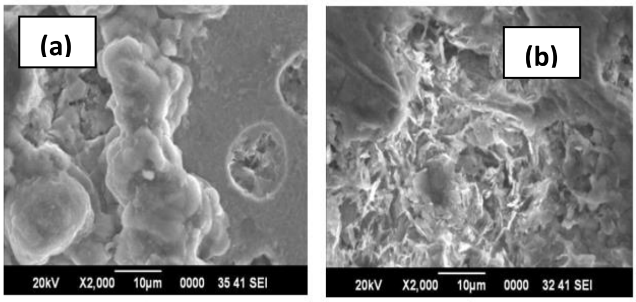

Fig.4: SEM microgrograph of steel 2 at (a) core and (b) Rim after exposure

TABLE 3.2: YS, UTS and % Elongation obtained

Alloy	YS	TS	% Elongation
Steel 1	580	645	16
Steel 2	565	612	18

3.1 Corrosion and Mechanical test

The strength of the test specimen decreases as the corrosion rate increases. Figure 5, 6 shows yield strength and UTS variation with corrosion rate. The figure clearly indicated that yield strength of steel bars decreases with the increase in the corrosion rate. These phenomena may be understood with the mechanism of corroded products formed on the surface of steel bar.

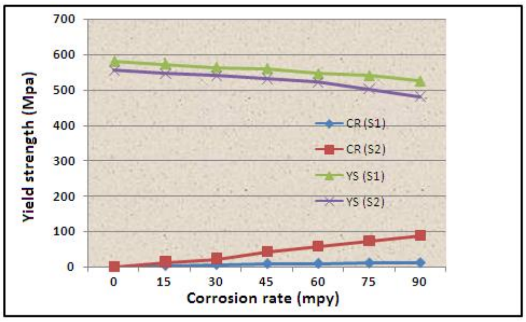

Fig.5: Yield strength of the TMT bar steel 1 and steel 2 with different corrosion rate

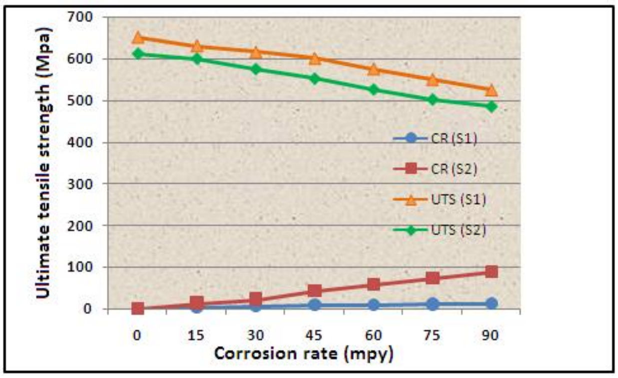

Fig.6: Ultimate tensile strength of the TMT bar steel 1 and steel 2 with different corrosion rate

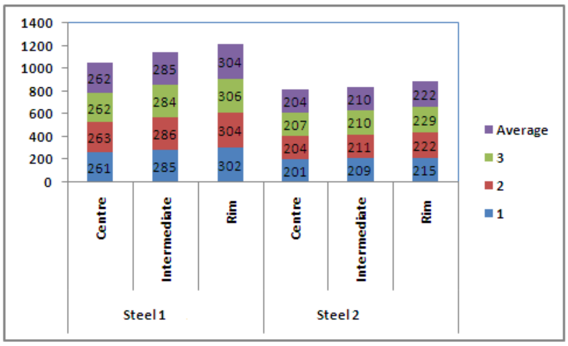

Fig.7: Hardness (HRB) of the TMT bar steel 1 and steel 2 at different region of the surface

Figure 8 below shows variation of elongation with corrosion rate. The figure clearly indicates that elongation of steel bars decreases with the increase in the corrosion rate. These phenomena may be understood with the mechanism of crack propagation on the surface of steel bar.

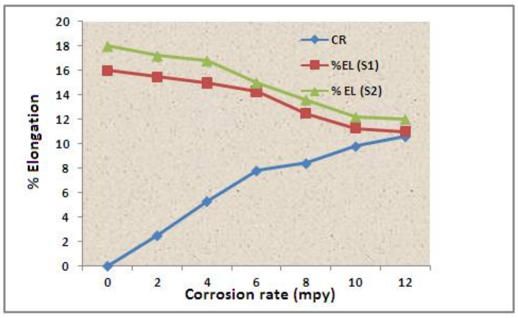

Fig.8: % Elongation of the TMT bar steel 1 and steel 2 with different corrosion rate

Failure of concrete structures due to corrosion of embedded rebars is a major problem causing significant loss of money and time. There is a need to fully understand the root causes of failure before the repairing for effective remediation. An effective method to measure corrosion is a fundamental requirement to avoid initiation of cracks and ultimate failure of the concrete structures. The degradation or deterioration of these structures is governed by several parameters such as moisture content, presence of oxygen, chloride ion, temperature and external load.

IV. CONCLUSIONS

In the present study, the experiment results on the mechanical properties of base material and corroded steel EQR tmt rebars were carried out at normal room temperature. The above shown results indicated that variation of elongation, nominal yield strength and nominal ultimate strength of steel bars with different obtained corrosion rate. The observation was made on the basis of results drawn and found that, when corrosion rate is small, the depth of rust deposited on the surface is very shallow and thus it reacted thoroughly on the surface and may be considered as uniform corrosion. Gradually, when the rate is faster it becomes serious and formed rust spot on the surface which created depth pit on some localized surface. As the localized corrosion is insidious in nature and can’t easily be predicated it reduces the nominal yield strength, nominal ultimate strength and elongation of steel bar with change in corrosion rate. Thus the coupling effects of corrosion on nominal yield strength, nominal ultimate strength and elongation variation of steel bar was more obvious. The pit formation and uniform nature of crack propagation, pit formation and deposition was shown in the micrographs of SEM.

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