A Review on Deterioration of Mechanical Behaviour of High Strength Materials under Corrosive Environment

Sunil Kumar S[1*], Neelakantha V Londe[2], Dilip Kumar K[3], Md. Ibrahim Kittur[4]

[1] Research Scholar, Dept. of Mechanical Engineering, MITE, Moodabidri, Karnataka, INDIA.

[2] Professor, Dept. of Mechanical Engineering, MITE, Moodabidri, Karnataka, INDIA.

[3] Professor, Dept. of Mechanical Engineering, SDIT, Mangalore, Karnataka, INDIA.

[4] Assistant Professor, Dept. of Mechanical Engineering, PACE, Mangalore, Karnataka, INDIA.

*Corresponding Author: sunilgooch@gmail.com, sunilkumar@mite.ac.in

Abstract. Surface corrosion has a major influence on ageing of high strength materials that leads to degradation in mechanical properties. Therefore,design of a component frequently implores the engineer to minimize the possibility of failure particularly by environmental deterioration. Effect of corrosive environment on high strength materials of Aluminum alloys and steels is studied. The influence of corrosion on material loss and deprivation of mechanical behaviour such as ultimate strength, yield strength and fatigue resistance arereviewed and presented.Salt spray test as per ASTM B117 and immersion in natural sea water are the usual practices followed to induce corrosion. It is evident from the literatures that corrosion has a significant effect on deterioration of mechanical behaviour of the materials.

Keywords: Corrosion, High strength materials, Mechanical behaviour.

1. Introduction

Engineering materials during their service life are exposed to mechanical failure due to major causes such as fracture, fatigue, creep, wear and corrosion. Materials do not reach their theoretical strength when tested practically. Therefore, the performance of the material in service is not same as expected. Hence, the design of a component frequently implores the engineer to minimize the possibility of failure particularly by environmental deterioration such as corrosion. It could be found that the concentration of chloride is more in offshore or marine environment that leads to chloride induced corrosion, a key cause of deterioration of structural materials such as steel. The effect of corrosion on structural materials in service life leads to mechanical failure [1, 2, 3].The structural Steel bars in reinforced concrete must possess high tensile strength because theyare usually subjected to tensile loads. Therefore, the corrosion of the reinforcing steel bars in concrete is primary cause for failure of concrete structures [4, 5]. The present days standards have led the structural steels to have load carrying capacity with respect to fatigue load that varies with time. However, a little work has been done on effect of corrosion on low cycle fatigue of structural steels.

The fatigue load on the structures causes sudden cracks on the surface which breaks the oxide layer and thus enhancing faster corrosion rate when compared with static loads [6-15]. Rain, fog and condensation due to temperature change are the causes for the formation of electrolytic layer on the

metal surface which results in atmospheric corrosion. The chlorides in the coastal region increases the conductivity of electrolytic film on the metals and tries to destroy the passivity, which is a cause for increase in corrosion rate [16-82]. Atmospheric corrosion monitoring sensors are used to measure the cause and property of electrolytic film [17]. Structural steels used in harbours, shipping, sheet piling will generally have cathodic protection which is effective only if properly maintained for a certain time period. However, some structures not only depend on time but there are other crucial parameters such as temperature, microbiological nutrients such as dissolved inorganic nitrogen by which the coated surfaces are also induced with corrosion thus leading to failure of the structures [18]. Corrosion results in failure of structures, leakages in pipelines, contamination of the environment which may me trivial but finally leads to loss of life at higher degree of occurrence [19]. Thus, it is evidenced from the literatures that corrosion is a vital reason for deterioration of marine and off shore structures.

2.Salt Spray Test

An extensive research is in development to identify the effect of salt spray on metallic materials such as steels,magnesium alloys and aluminum alloys. Charis A. Apostolopoulos has examined the effect of corrosion on mechanical performance of B500c steel bars. The tensile specimens are immersed in salt spray chamber for a period of up to 120 days as per ASTM B117 [15] specifications [67]. The salt solution contains 5 % of NaCl in 95 % of distilled water with a pH range of 6.5 to 7.2 and the temperature in the salt chamber is about 35 °C [15]. The mass loss is found to be linear with respect to time of exposure with about 14 % of mass lose at the exposure time of 120 days. Increasing tendency of reduction in yield strength and ultimate tensile strength is observed. At the end of 120 days of exposure, the yield strength and the ultimate strength are reduced by 32 % and 23 % respectively [1] as shown in the Fig.1.

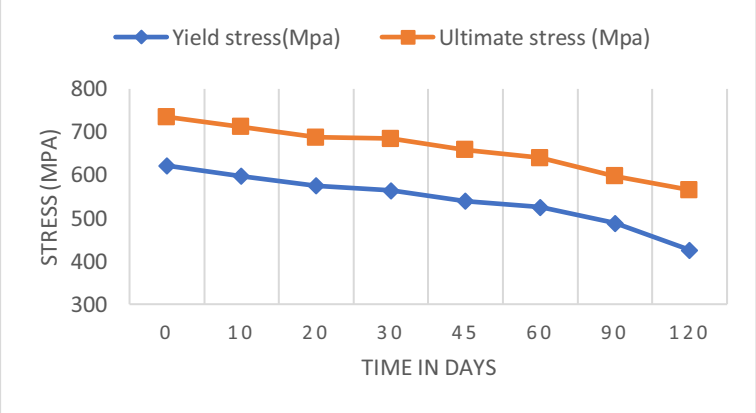

Fig.1: Influence of exposure time on yield stress and ultimate stress

Experiments have been carried out to find the effect of salt spray on reinforcement steel bars of BSt 420 as per ASTM B117 [67]. There is increasing tendency of decrease in mass, yield stress, ultimate stress and elongation at failure with increase in exposure time [2]. Three forms of corrosion such as general, pitting and filiform are quantified by optical microscopy, laser profilometry and SEM on the material of extruded AM30 magnesium alloy. Both salt spray and immersion test have been carried for a period of about 60 hours. It is observed that immersion has higher influence on general and pitting corrosion whereas filiform corrosion is more in salt spray environment [3]. Reinforcing steel bars of S500 and B500 are tested for their tensile strength after exposure in corrosive atmosphere of artificial salt spray chamber. There is reduction in mass of both the materials and thus the diameter of the

tensile specimens is decreased with increase in exposure time. It is observed that there is decrease in yield stress and ultimate stress which is displayed in Fig.2. Elongation at fracture and strain energy density are also found to decrease with increase in exposure time [4].The effect of salt spray on low cycle fatigue behaviour of S500 steel bars is presented. The alternating load of low cycle fatigue has resulted in formation of surface cracks which affected the oxide layer and resulted in faster corrosion rate. It is observed that there is gradual reduction in both loadbearing ability and available energy and also proved the reduction in the ductility of the material [6].The evaluation of corrosion is usually made by weight loss of the material [1-15].

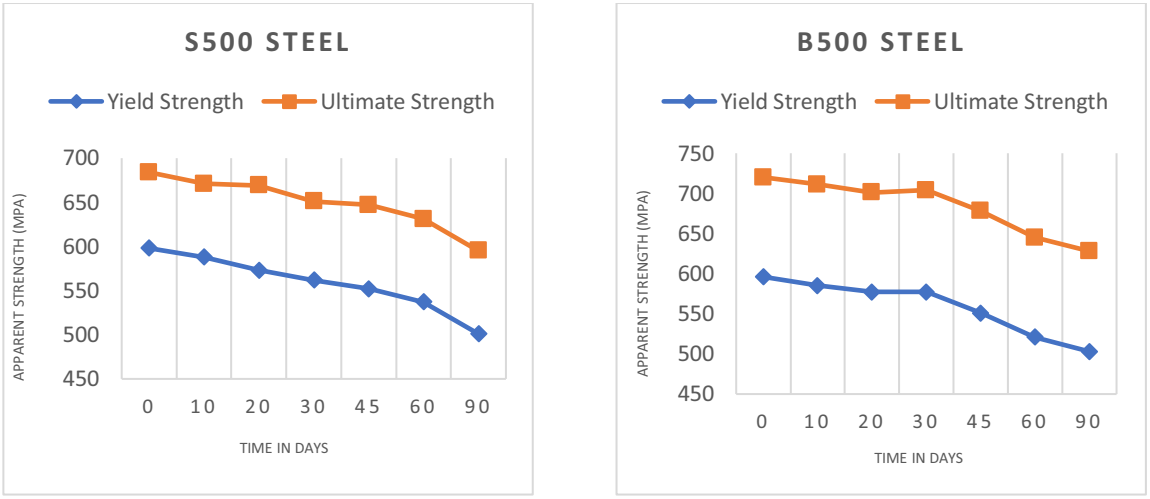

Fig.2: Variation of Apparent Strength with exposure time.

3.Atmospheric Corrosion

Research is under evolution on the atmospheric corrosion particularly in coastal regions. This type of corrosion is not accelerated as in case of salt spray chamber, but it is more significant due to naturality. Atmospheric corrosion is the result of chlorides of aqueous precipitation such as fog, salinity in marine environment, precipitation of dew due to humidity change. These chlorides adhere to the metal surface and results in corrosion [7- 82].Rate of atmospheric corrosion can also be monitored in a short span of time by using corrosion monitoring sensor which works on galvanic current rather than exposurefor a longer time [16].The rate of corrosion in structural steels in sea water is increased by nutrient concentration such as dissolved inorganic nitrogen. It is predicted that at elevated nutrient concentrations which can be equalized with pollution of sea water, corrosion losses are determinably higher when compared with nonpolluted sea water [17].The passive layer on the material surface breaks down at some localized points, referred to as pitting corrosion of marine and offshore steels structures. The cause for pitting, pitting depth analysis and related mathematical relationships are primary factors to be considered [18].

Jyoti Bhandari et al [19]. has reviewed the literatures on pitting corrosionto identify and evaluate the parameters thataffect pitting corrosion in off shore and marine environments and has depicted thatpitting is one of the most destructive corrosions and the various factors which affect the pitting corrosion are atmosphere, temperature, pH level, splash etc. However, there are less attempts made on probability modelling for corrosion as a function of time in the recent years.

The materials of air craft structures likewise degrade under corrosion.Pantelakis et al [20]. have evaluated the tensile behaviour of high strength aluminum alloys of 2024, 8090, 2091 and 6031 after corrosion. Mechanical degradation is observed proving decrease in yield strength and ultimate strength with enhanced intergranular cracking when exposed to longer time. However, there is noticeable volumetric embrittlement at lesser exposure time.Corrosion also has a significant effect on wear characteristics of materials [33, 34]. The authors have examined the various behaviour of corroded materials with respect to time of exposure [21 – 82].In this way corrosion of high strength materials is an extensive topic that researchers are working on, but the evaluation of mechanical degradation of materials due to marine chloride is an emerging research study.

4. Influence of corrosion on fracture properties

Fracture mechanics is the branch of solid mechanics which explains the mechanical behaviour of bodies having cracks under different loading conditions. The past experience of structural failures and the desire for increased safety and reliability of mechanical systems like automobiles, aero planes, bridges, pipelines, pressure vessels and components of nuclear plants etc. have led to the development of different fracture criteria. Fracture Mechanics deals with the fracture properties of the above said structural materials under corrosive environments. It is concerned with the study of the initiation and propagation of cracks. The fracture properties such as fracture toughness, fatigue crack growth rate and threshold stress intensity factor are important material properties considered in machine design based on fracture Mechanics [83-103].Research is under advancement for predicting the failure of structural materials by the mechanism of Stress Corrosion Cracking (SCC).

Iliyasu I et al [83] have studied the susceptibility of austenitic stainless steel to stress corrosion cracking in sodium chloride. The stress corrosion cracking (SCC) behaviour of type 304 austenitic stainless steel in Sodium Chloride (NaCl) has been investigated. This was done by exposing the entire specimen to the corrosives (NaCl) at concentrations of 0.3M, 0.5M, 0.7M, and 1M. After every seven days one specimen from each of these corrosives is removed and loaded on a tensometer until fracture. Percentage elongation and percentage reduction in cross sectional area are used to investigate the SCC behaviour of the steel. The ductility of Type 304 Austenitic stainless steel decreased with increased exposure time and concentration.

Gamboni et al [84] have studied the effect of salt-water fog on fatigue crack nucleation of Al and Al-Li alloys. Fatigue and corrosion-fatigue tests are performed to quantify the fatigue properties of AA2524-T3 and AA2198-T851 Al alloys. High cycle axial fatigue tests are carried out under air and salt-water fog conditions. The results indicate that the saline environment has a deleterious effect on the fatigue life of aluminum alloys.

Samir Milad Elsariti et al [85] have studied the behaviour of stress corrosion cracking (SCC) of austenitic stainless steels of types 316 is investigated as a function of applied stress at room temperature in sodium chloride solutions using a constant load method. There is a high susceptibility of SCC on failure of the material.

SCC is characterized by synchronised action of stresses and corrosion effect and is one of the principal failures of the structures particularly in marine environment which causes catastrophic rupture and thus leads to economic losses [103]. Generally, the surface of the material is susceptible to SCC because of chloride concentration. It is evident from the literatures that materials such as structural

steels have experienced failure due to SCC in marine environment [83-103]. However, the SCC mechanism and the study of fracture mechanics due corrosion needs further investigation.

5. Conclusion

There are several literatures that explains about the influence of corrosion on the mechanical behaviour of the high strength materials such as structural steels. This article reviews the identification of various conventional and recent methods to model the corrosion and its effects. It is obvious from the literature that there are appropriate methods such as salt spray test as per the ASTM standards B117 to perform corrosion test on the materials and thus recon the rate of corrosion. It is also evident that the corrosion tests can be performed by immersing the specimens of the materials in natural sea water. The following conclusions could be presented from the literatures.

- The factors that influence the corrosion are temperature, pH, time, rain, fog, micro biological nutrients such as dissolved inorganic nitrogen, salinity, humidity etc.
- The chlorides in the coastal region increases the conductivity of electrolytic film on the metals and tries to destroy the passivity, which is a cause for increase in corrosion rate that leads to chloride induced corrosion, a key cause of deterioration of structural materials such as steel.
- The literatures on salt spray test has proved that the corrosion strongly affects the mechanical properties of structural materials. It is manifested that there is increasing tendency of decrease in mass, yield stress, ultimate stress and elongation at failure with increase in exposure time. There is gradual reduction in both load bearing ability and available energy and also reduction in the ductility of the material.
- The literatures on stress corrosion cracking (SCC) prove that the structural steels have very high susceptibility for SCC in marine environment and the materials exhibit brittle failure under prematured crack growth. The fracture strength of the corroded specimens is drastically decreased due to pitting corrosion which is a key influence for early fatigue crack growth initiation.
- However, the SCC mechanism and the study of fracture mechanics due to corrosion needs further investigation. The detailed study of fracture parameters such as threshold stress intensity factor, fatigue crack growth, fracture toughness, stress triaxiality, crack tip opening displacement etc of the structural materials after sea water immersion which is equivalent to corrosion in marine environment could be considered as the future scope of this study.

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