A critical review on wear and corrosion of carbide free bainitic steel

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Abstract. Different research on wear and corrosion of CFB (carbide free bainitic steel) over the past two decades has enabled a better understanding and advanced applications of CFB steel. With the help of advanced testing techniques, and equipment the detailed study of microstructure and nanostructured steels has been possible. The earlier years were focused on comparison of the bainite steel with the steel which is quenched and tempered (QT) for identifying the wear tendencies and comparison between carbon free bainite and martensite for the corrosive behavior of the carbide free bainitic steel. Later the trend shifted towards the nanostructured analysis from microstructure analysis with the improvement in the instruments. Advancements like HT-CAT i.e., high temperature continuous abrasion tester have an important role to play, the mechanism of material removal rate studied. There has also been development in alloying the bainite to reduce the corrosion rate and give more strength. Current trends in the form of study of wear and corrosion of carbide free bainitic steel and future needs are discussed hereby.

Keywords: Carbide-free bainite steel; heat-treatment; rolling/sliding wear; friction; mechanical properties

1. Introduction

Wear and corrosion are a matter of concerns for users for a very long time starting from the Iron Age where tools are made up of the metals and their sharpness is needed to be maintained for hunting, to the current era of carbide free bainitic steel. Due to the combination of high strength and ductility alongwith the low production cost CFB steels are considered as a promising class of steels [1].
Figure 1. Observations of CFB through the optical microscopy, the chemical composition was Fe-1 C-2.0Si-4.0Cr alloy which went under austenitization at 110° C for 10 minutes and then treated isothermally at a temperature of 300° C for 30 minutes [2].

Figure 2. Observations through optical microscopy. In the a part granular bainite has been shown while in the b part the granular structure was focused whose chemical composition was 0.12C-3.0Mn-0.001B-Fe alloy which is austenitzation is performed at a temperature of 920° C and cooled at high and low rate in the (a) and (b) part respectively [2].

According to the American Society of Testing and Materials International [3], wear is defined as damage to a solid surface caused by relative motion between that surface and a contacting substance or substances, which results in a progressive loss of material and the definition of corrosion is the deterioration of a material, usually a metal, provoked by a chemical or electrochemical reaction by its surroundings. Therefore, in this review, the papers which adheres to the definition of wear and corrosion of the carbide free bainitic steel are observed.

This paper is concerned with bainitic steel because the carbide-free bainitic steels have great potential of performing during wear because of better strength and ductility [4]. By transformation at homologous temperatures $T/T_m$ 0.25 the bainite formation can take place with 2.3 GPa ultimate tensile strength and a toughness of some 30MPam$^{1/2}$ in silicon rich high-carbon steels, where $T_m$ can be defined as the absolute melting temperature. [5-7]

In industrial scenario where mechanical systems or moving parts or machine assemblies are involved approximately half of the material loss occurs because of the abrasive wear. For the prolong services of these components the steel which are used for them are quenched and tempered [8]. The carbide free bainite (CFB) can be defined as the bainitic microstructure obtained without the precipitation of carbides on austempering the steels which contains more than 1.5% Si [9, 10]. The automotive industries and the railways have a huge possibility of some application of CBD rather than using the QT steels [11]. CBD
has two phases in it, one is the bainitic ferrite and other is the retained austenite. The carbon content of retained austenite is high, and as a result it has been stabilized at the room temperature. Further the retained austenite can be one of the two types either it could be the undesirable blocky austenite or it could be a film covering the bainite. The undesirability of the blocky austenite is due to its fast transformation into the brittle martensite when it is under strain resulting in reduced toughness and in another case where austenite covers the bainite as film the strain requirement increases to convert it into martensite and hence the strength is increased.[12]

Apart from wear another important factor which plays a vital role in the deterioration of the material is the corrosion. Corrosion shows a tremendous loss and thus it is needed to be reduced. Corrosion is dependent not only on the material but also on the surrounding, while nearly all situations are corrosive to some level, inorganic materials are more corrosive than organic materials in general. [13]

Rebar corrosion is one of the major player in the degradation of RCS (reinforced concrete structures) [14]. In the recent times many giant marine RCS are manufactured and needed, the seawater possesses huge concentration of the chlorine and thus the risk of corrosion increases. Therefore, the need for better strength and corrosion resistant rebar are demanded [15-17]

2. Current trends in wear of carbide free bainite steel

High strength bainitic steel is in trend due to its desirable mechanical properties which are required in heavy wear applications. The work of P.H. Shipway [18] is a comparison of wear resistance between two steels, one is the isothermally formed bainite and other one following the heat treatment process like quenching, tempering, normalizing etc. It also examines that what effect does the temperature of transformation occurs on the bainite’s resistance to wear. In the previous studies shows that when compared to pearlitic samples the bainitic steels have the poor wear resistance, while this works shows that microstructure and the transformation conditions are the main factors upon which the resistance of the bainitic steel depends. At lower transformation temperature bainitic is fine, hard and tough. Here the formation of martensite and cementite can be suppressed exhibiting better wear resistance LC Chang's [19] investigation of the rolling/sliding wear of carbide free high silicon bainitic steels (as they were used in rail applications) is important when analysing wear patterns. In this research also he shows that the resistance to wear that is shown by the bainite is similar to pearlitic one. The results of this research shows that lower wear rates are exhibited by the harder materials and in the microstructures the inclusions and allotriomorphic ferrite were detrimental wear.

The superior mechanical properties of bainite are due to its finer microstructure as encountered by the Alejandro [20] in his research by changing the temperatures and sliding distances to examine the dry rolling/sliding wear of Si alloyed carbide free bainite steel. Spring steels were used after austempering at different temperature and sliding wear tests were performed for different cycles. Its results shows that above 2500 cycles the initial roughness doesn’t affect the wear rate. Also in every case the lowest rate of wear was exhibited by the 250 0C austempered specimen which is because of its fine microstructure.

Further the trend goes towards the nano structured carbide free bainitic steels where wear analysis is performed by A. Leiro[21] under dry rolling-sliding conditions. The specimen was made by transforming the steels with 0.6to 1 % carbon between 220 to 270 C. Even at the same hardness level the nano structured steels exhibits the wear rates which were lower in comparison to conventional CFB steels. Similar study with added evaluation of fatigue application over High Si C steel nano structured bainite was performed by T. Sourmoil [22]. Similar trend as the previous studies was shown by him confirming exceptional wear resistance in High silicon cast bainitic steels. He also anticipated from the results that better wear resistance can be enabled by increasing the hardness and retaining carbide free microstructure.

Further the trend goes towards wear testing in the 3 body abrasion type at room temperature and at elevated temperature. Sinuhe [23] performed this test by HT-CAT i.e., high temperature continuous abrasion tester at 25, 300 and 500 0C and shows the dependency of wear rates on note only on the
hardness but also the toughness. Multiple results shown in this research confirms the previous trends and also helps in the determination of the new ones. For example, that as the results shown by sample AT300 which had lower toughness indicating that at 500° C. Toughness also has a role to play because at this temperature parts of microstructure get high deformation environment and goes into recrystallization. The material removal mechanism was micro ploughing, micro cutting. At 300° C surface oxidation also aided in the removal of metallic material.

The trend leads us to the analyze the effect of the retained austenite stability in the bainite by performing an impact abrasion test on it done by Binggan Liu [24]. The results shows that stable retained austenite has better wear resistance, and it tends towards decreament the possibility of the transformation of retained austenite to martensite increases. In addition to the improved hardness the retained austenite helps in resisting the crack opening and propagation. It also confirms the previous study material removal mechanisms were microcutting and micro cracking in the impact abrasive wear. The stability is better with the lower austempering temperatures thus providing better wear resistance. Another key factor was the fracture toughness which is reduced with the greater retained austenite stability.

3. Current trends in corrosion of carbide free bainitic steel

The trend started from 2007 where B.Z. Bai [25] studied the carbide free bainite with duplex phase for its corrosion fatigue properties. He shows that after austenizing, tempering at 280° C or 370° C for the specimens which were air cooled showed better corrosion fatigue. He also shows that the decreased hydrogen brittle sensitivity is due to the RA (retained austenite) which functioned as a hydrogen trap. The high strength steel CFB also has filmy RA in the microstructure increasing the boundaries in the steel causing the changes in the corrosion fatigue crack orientation and turning of propagation path resulting in the improved corrosion fatigue properties.

The effect of the microstructure as corrosion fatigue behavior of carbon free bainite/martensite were studied by XU Lei [26]. Comparison between the full martensite and carbon free bainite/martensite were performed. Irrespective of the temperature of the tempering the σ 1-c of CFB/M was higher than 150 MPa and for full martensite it was higher than 100 MPa. The rate of crack propagation in the carbon free bainite/martensite is also observed less. Due to the refined microstructure of the CFB/M the trapping of hydrogen is more therefore lower embrittlement sensitivity.

The trend from here goes towards finding the balance between strength and corrosion rate for different applications like marine concrete structures for example the steel rebar. Dan Song [27] studied the ferrite/bainite duplex steel rebar having alloyed with ultra low Cr-Mo. The corrosion behavior and its mechanism were studied and the conclusions from the tests specifies that rate of corrosion of Cr-Mo alloy steel structure in NaCl solution was better than 403SS i.e. satisfactory. The reason behind this is the Cr dominated passive film which inhibits the corrosion medium to enter inside. Because the bainitic phase (40%) has lower Cr-Mo content and higher number of crystal defects (such as grain boundaries, intergranular dislocations, subgrain boundaries) than the ferrite phase in steels, the tendency of corrosion is higher. When the bainitic phase is used as anode and the ferrite phase is used as cathode in a microgalvanic corrosion test, at first the passive film which is on the bainite phase breaks thus initiating the corrosion of Cr-Mo duplex steel. This is the effect of RA on wear resistance of multiphase steel and CFB steel [28-29].

4. Conclusion

Major advancement has been made in the research of the wear and corrosion of the carbide free bainitic steel like the comparison techniques, advanced instruments, advance equipments, methods etc. Following conclusions can be obtained:

1. Research in the starting phase rely on the comparing the properties with different metallic phases but later it got improved by advancements where the focus changed to microstructural study, and to the nano level. The research of the above discussed researchers produced the major advancements in obtaining the wear and corrosive properties of the carbon free bainitic steel. Different factors on which the wear and corrosion depends were identified by these studies like hardness, toughness, fatigue applications etc. These studies witnessed the use of impact testing, three body abrasion testing, and equipments like HT-CAT resulting in better results and conclusions about the bainitic steels.
2. The carbide free bainitic steel possess huge potential with respect to the application phase, it can not only has the ability to change the rails scenario but also has huge marine based applications. The only need is to explore the area of wear and corrosion carbide free bainitic steel completely. Although in field of wear of carbide free baintic steel a significant work has been performed still a lack of collaborative study on it that includes all the factors affecting the wearability the material has not been performed. We observed that not a single impactful study that is focused totally on the corrosion of the carbide free bainitic steel has been performed

3. With the huge possibility of application and the present declining trend of research in the corrosion of carbide free bainite steel one might expect that the full potential of this material is yet to be discovered.

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