International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 09 Issue: 05 | May 2022 www.irjet.net p-ISSN: 2395-0072

Analyzing the Effect of Alloying Addition in Steel samples

Qazi Mohammad Khalid Mehraj[1], Abhishek Thakur[2]

[1]M.Tech Scholar, Universal Institute of Engineering & Technology, Lalru
[2]Assistant Professor, Universal Institute of Engineering & Technology, Lalru

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Abstract: The alloying addition to steel is important to improve its properties according to the applications. There are number of applications for which the superior surface properties are required. The surface properties may include the hardness, wear resistance, friction, corrosion resistance etc. In the present study, the work focuses on the hardness and corrosion resistance. Hardness is considered as resistance to indentation which can be increased by number of methods, out of which one is to refine the grain boundaries that restrict the dislocation movement and increase the hardness. The corrosion resistance is considered as the resistance to chemical action taking place at the surface of any sample. The corrosion resistance can be increased by passivating the samples easily and effectively by stable passive film. The Ti addition was considered beneficial in the present study to enhance the hardness, corrosion resistance and reducing the chances of crack formation in steel by avoiding the formation of harmful intermetallics of other alloying elements. The hardness value was determined for all the samples. The corrosion resistance was analyzed in H_2SO_4 solution for observing the suitability of material in harsh environments. The hardness and corrosion resistance increased with the addition and increase of the Ti content.

Keyword: Hardness, Corrosion, Passivation, Tafel

1. Introduction

Steel is an alloy that consists of iron and carbon and may have up to 2.1 percent carbon by weight. Steel may also include a few additional alloying elements, such as manganese, chromium, nickel, and so on. These elements are added to enhance the qualities of steel so that it may be used for the ultimate use that was envisioned. Steel has several qualities in addition to its tensile strength, including ductility, resistance to corrosion and wear, red hardness, hardness, weldability, fatigue resistance, and red hardness. Steel is one of the most extensively used alloys in the world due to its inexpensive cost and several desirable qualities, such as those described above. Steel is the most widely used industrial material due to the combination of its qualities and the fact that it is relatively inexpensive. Steel's uses are diverse. Its dependability is enhanced by the fact that, in comparison to other metals, it is found in relatively large quantities. Steel is used in the building industry, vehicle manufacturing, shipbuilding, infrastructure development, the military, as well as the production of tools, household appliances, machinery, and machine tools. Steel may have its characteristics improved via the application of methods called heat treatments.

Since the 1870s, the production of steel ingots has been ongoing. Pouring-sectioning experiments were carried out at astronomically inflated costs in order to explore the solidification sequences, which were necessary in order to comprehend the solidification behavior of such ingots at the time [1–4]. For the purpose of evaluating the ingots' structural integrity, composition, and soundness, several dozen ingots ranging in weight from a few hundred kilos to several hundred tons were carefully poured and sectioned.

There are still a few solidification related phenomena that are not completely known, despite the fact that the majority of the essential information about the manufacturing of steel ingots has been thoroughly established. As a result, it should not come as a surprise that expensive pouring-sectioning experiments are periodically carried out even in the modern day. [5–9] The experiments carried out now are different from those carried out in the past because contemporary techniques of analysis are used in order to get additional information about the tests' structural and compositional components. The development of new alloying ingots for specific applications is one of the reasons why those experiments need to be repeated; however, an even more important reason is to evaluate the efficacy of numerical models, which are thought to one day be able to take the place of those taxing experiments. In this respect, modeling studies and numerical simulations of ingot castings have emerged as the most cost-effective way; yet, there is still a lack of trust in the findings produced by these methods. In the 1960s, numerical simulation was initially put to use for the purpose of modeling the behavior of hot metals for the very first time. [10]

The finite difference approach was used to study the solidification sequence in the steel ingot, and it was able to solve a straightforward issue involving heat conduction. It is difficult to believe that a computer from the 1960s was capable of solving the issue of ingot solidification, particularly in light of concerns that are made now about the computing power of current computer systems. The first simulation experience for ingot casting was actually successful, and it was applied to determine the optimal delay for charging the soaking pits. It was also used to study the influence of the holding time of the ingot in the molds, as well as the time between stripping and charging. Finally, it was used to determine the optimal delay for charging the soaking pits. Numerical models with a wide range of simulation and modeling capabilities have been produced over the course of the last half century as a direct result of advancements made in computer hardware and numerical algorithms. These models have been used to ingot casting procedures. For instance, the thermal field based solidification model has been implemented for decades in commercial codes, such as ProCAST[11] and MAGMASOFT[12], and used by metallurgists to evaluate and optimize the casting parameters, mold, and hot top design. On the other hand, some other sophisticated solidification models that take into consideration the multiphase transport phenomena have been developed and used to enhance the understanding of the macrosegregation mechanisms.

2. Material and Methods

2.1. Sample preparation

In the present study, the low carbon steel samples were investigated. The Ti addition and variation was done in low carbon steel to analyze its effect. Moreover, two Ti-containing steel samples were also investigated simultaneously with 0.3% Ti and 0.6% Ti, and these samples are referred in this thesis as $Ti_{0.3}$ and $Ti_{0.6}$. The Ti-free sample is referred as Ti_0. In the present work, the handsaw was used to cut the sample into pieces for characterization. The emery paper was placed on glass to get flat and hard surface for preparing the sample for characterization. The sample was polished on emery papers from 220 to 1000 grit size emery paper in a sequence. After working on emery paper, the samples were finally polished on alumina paste containing velvet cloth. Finally, the samples were washed properly with water.

2.2. Characterization

2.2.1 Optical microscopy

Optical microscopy is a method for seeing a sample up close using visible light and a magnifying lens. This is the classic type of microscopy, which was developed before the 18th century and is being used today. Optical microscopes come in a wide variety of designs. They may range in complexity from very simple to quite intricate, with increased resolution and contrast. Optical microscopes come in a variety of shapes and sizes.

2.2.3 Hardness testing

Hardness is a quality of a substance, not a physical feature in and of itself. Indentation resistance is measured by measuring the permanent depth of the indentation, and it is also referred to as abrasion resistance.

The hardness of samples was tested using hardness tester with 3 kg of load for 10 seconds and then anayzing the diagonals of indent on the surface. After, analyzing the diagonals, the hardness value was calculated and the effect of Ti addition was observed.

2.2.3 Tafel performance

The corrosion behavior was analyzed using potentiostat in 0.1 molar H_2SO_4 solution for testing the samples in harsh conditions. The saturated calomel electrode was taken as a reference electrode in this study. In other words, the potential readings were taken with the reference to saturated calomel electrode. The platinum was used as counter electrode that completed the circuit between sample and corrosive medium. When the sample surface reacted with solution, then the corrosion parameters such as corrosion current density (I_{corr}) and corrosion potential (E_{corr}) were recorded by potentiostat. The corrosion current density estimates the number of ions and electron exchange between sample and corrosive medium, which means that it is kinetic factor in corrosion behavior. The corrosion potential tells about the tendency of sample to corrosion. More the potential, more the sample is corrosion resistant. Therefore, it can be said that for overall corrosion resistance, corrosion potential should be high and corrosion current density should be low. The Icorr, Ecorr and corrosion rate are determined by fitting the potentiodynamic corrosion curves of samples.

3. Results and Discussions

3.1 Micrograph of Steel sample

Figure 1 shows the appearance of deep surface crack on Ti-free steel sample.

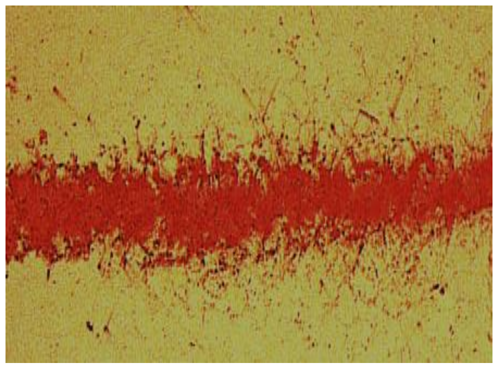

Figure 1 Optical micrograph of sample with crack

The presence of N and C along with other alloying elements shows that there are some nitrides or carbides due to which the defect has developed. There is need to add some alloying element such as Ti, V etc. which can form lesser harmful coarser nitrides or carbides fast, due to which the chances of crack can be reduced.

Then the Ti-containing samples were investigated and the same procedure was followed. The minor defects were removed using grinder and magnetic particle inspection was repeated. $Ti_{0.3}$ steel sample showed the presence of crack but the depth was decreased as compared to Ti-free alloy. The $Ti_{0.6}$ sample showed insignificant presence of crack. This showed the positive effect of Ti addition to steel and decreased the cracks on surface.

There is a reason of positive effect of Ti in decreasing the cracks. Ti forms stable compounds with oxygen, carbon, nitrogen, and sulfur. Ti made coarser precipitate along grain boundary than Al or other elements due to which the crack was not much propagated. It is sometimes used in steelmaking because of its property for fixing of these elements in order to reduce their harmful effects. Ti is also used for the purpose of grain refining in many steels. Ti also helps in increasing the strength and decreasing the density of alloys.

4.2 Hardness

The hardness of Ti-free and Ti-containing steel samples was estimated. The addition of titanium influenced the hardness as shown in Figure 2. With the addition of Ti, the hardness increased. The reason can be explained based on the ability of Ti to refine the grains. Due to grain refinement, it was difficult to penetrate in the surface for any indenter. Therefore, the hardness value increased with the addition and increase of Ti content.

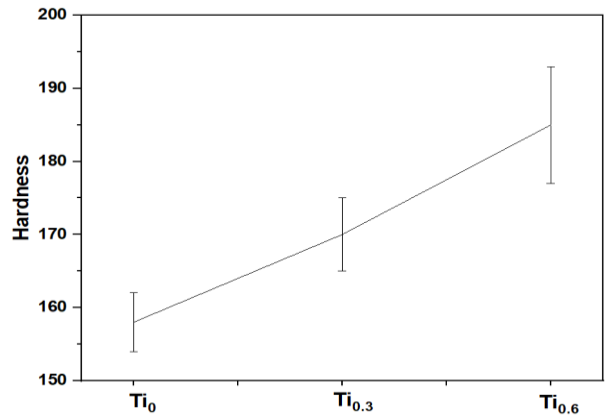

Figure 2 Hardness of steel samples

4.3 Corrosion behavior of steel samples

In the present work, the Ti-free sample showed -775.38 mV corrosion potential as shown in Figure 3. With the addition of Ti, $Ti_{0.3}$ sample showed increased corrosion potential to -706.32 mV. By increasing the Ti content in $Ti_{0.6}$, the corrosion potential further increased to -675.97 mV. It clears that the corrosion tendency in H_2SO_4 decreased with the addition and increase of Ti content.

The I_{corr} for Ti-free sample was 0.019 A in H_2SO_4 solution. By adding Ti in $Ti_{0.3}$ sample, the I_{corr} value decreased from 0.019 to 0.010 A. The I_{corr} value further decreased to 0.006 A with further increase of Ti in $Ti_{0.6}$ sample. It indicates that the corrosion kinetic was controlled with the addition and increase of Ti. After corrosion tests, the corroded surfaces were analyzed by optical microscope. The most of the surface of Ti-free sample was corroded in the corrosive medium as shown in Figure 4. The Ti-containing samples showed relatively lesser corrosion as shown in Figure 5 and Figure 6.

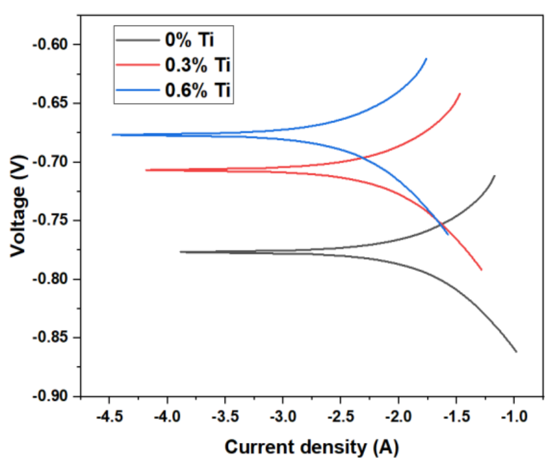

Figure 3 Corrosion curves of steel samples in H_2SO_4

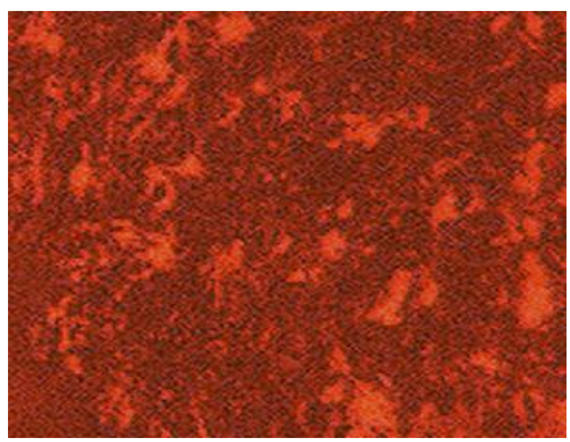

Figure 4 Micrograph of Ti_0 sample after corrosion

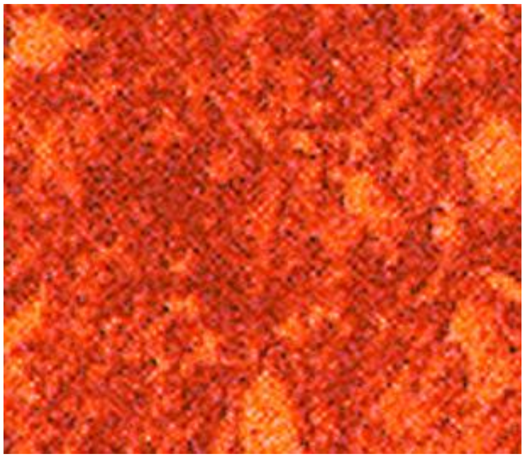

Figure 5 Micrograph of $Ti_{0.3}$ sample after corrosion

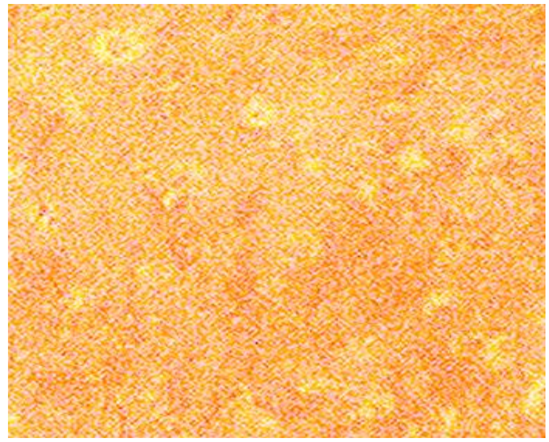

Figure 6 Micrograph of $Ti_{0.6}$ sample after corrosion

4. Conclusion:

The present thesis deals with analyzing the effect of Ti addition in low carbon steel. Ti was added to steel samples because Ti reduces the cracks by reducing the negative effect of other alloying elements and trapped gases. The hardness and corrosion properties were also investigated in the present. The addition and increase of Ti content resulted in increasing the hardness of samples continuously because Ti has ability to refine the grains, which restrict the movement of dislocations and hinder the penetration of any indenter. The Ti addition also increased the corrosion resistance in H_2SO_4 solution.

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