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Analyzing the Heat Treatment Flaws in Carbon Steel

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Abstract: Heat treatments are considered as one of the most important topics that arise in the field of Mechanical Engineering, which aims to produce some new properties for the metal, in order to use in several industries. Through this research, the types of carbon steel were identified, which included three types with the percentage of carbon that ranges in it. It accompanies the heat treatment of carbon steel, through which we got acquainted with the defects that accompany the heat treatment process of the metal, and the types of heat treatments were discussed, and each type was detailed through it. The significance of heat treatment—which is required for the development of current metals—emerged in this study, and the shortcomings in the heat treatments of carbon steel were investigated.This investigation revealed certain flaws that had to be avoided in the thermal treatments of steel.

Keywords: Heat Treatment, Carbon Steel, Flaws

1. Introduction

Applied to change the microstructure, mechanical properties, and performance characteristics of the material, heat treatment is a necessary process in the manufacturing and improvement of carbon steel. The kind of metal and the intended properties determine the different heat treatment methods. Manufacturers have to choose the suitable heat treatment technique to meet their particular needs [1]. Using a scientific management strategy to the heat treatment process will help to reduce the deformation of metal components[2].

Depending on the use, producers want to get desired qualities such improved strength, hardness, ductility, or toughness by precisely managing heating and cooling rates. On the other hand, incorrect heat treatment could cause many flaws in carbon steel, therefore degrading the quality and use of the material. From surface flaws like scale and decarburization to structural problems including grain development, quenching fractures, and unequal hardness distribution, these flaws may vary. Such flaws not only compromise carbon steel's mechanical qualities but may also cause failures in important uses, particularly in the building, automotive, and aerospace sectors [3]. Reliability of carbon steel products depends on an awareness of the kind, causes, and preventability of these flaws. This work investigates the typical flaws in carbon steel heat treatment techniques by looking at variables like temperature variances, cooling rate differences, and chemical reactions during treatment. By use of fault analysis, the research aims to maximize heat treatment techniques and thereby enhance the performance and safety of carbon steel in industrial uses. Many studies have looked at how heat treatment flaws affect the properties of carbon steel, therefore improving knowledge of the sources, techniques, and solutions for these issues. Previous studies mostly focused on the impacts of temperature control, cooling velocities, and environmental conditions during heat treatment, therefore highlighting key flaws compromising the performance of steel.

Of all the groups of metals now in use, one is very large. These are known as ferrous metals and indicate "containing iron". This category is important as all steels are among the most flexible and often used materials in modern life [4]. Among the ferrous metals category, there is a significant and extensively utilised subgroup known as carbon steel. Carbon steel is classified into three primary varieties according to carbon content.

Low-carbon steel (mild steel): Contains less than 0.3% carbon; known for its ductility, toughness, and weld ability.

I. **MEDIUM-CARBON** steel: features a balance between strength and ductility, making it appropriate for mechanical components; contains 0.3% to 0.6% carbon.

II. **HIGH-CARBON STEEL:** CONTAINS 0.6% TO 1.4% CARBON, WHICH IS USED OFTEN IN CUTTING TOOLS AND TOOLS DUE TO ITS HARDNESS AND RESISTANCE TO WEAR.

2. defects in heat treatment of carbon steel

The heating and chilling process is referred to as "heat treatment" of carbon steel, and it is used to accomplish specific microstructural characteristics for a diverse array of applications [6]. The procedure is considered defective if the necessary properties and microstructural features do not align with the criteria. Sometimes, despite meticulously adhering to all processing stages, the properties do not meet the criteria. The issue may be related to the composition of carbon steel or the design of the material, which can result in heat treatment defects. It is preferable to select the primary material and part design in order to achieve the desired properties [7].

Heat treatment defects that may arise during the heat treatment process include::

2.1 Soft Spots (Defects of Heat treatment)

Occasionally, the surface hardness of carbon steel may vary from one region to another after it has been quenched from the austenitizing temperature. Soft Spots are the term used to describe the variation in hardness in quenched steel from one point to another.

In the industrial sector, the Brinell hardness test is frequently implemented for substantial components that lack surface finishing. The Rockwell hardness test is employed for produced parts that are deemed non-destructive and will not impact the surface characteristics of steel parts. The Vicker hardness test is employed for laboratory testing and the determination of the specific hardness of phases in steel.

There are numerous potential causes of spongy areas in steel, including::

- **Problem with Quenching media:** that the critical cooling rate in a specific area is reduced by the formation of a vapour blanket stage in various media, such as water. This leads to defects in the heat treatment process, as it results in reduced martensitic formation and hardness in specific regions.

The generation of soft areas in carbon steel can also occur as a consequence of high quenching media temperatures or improper agitation.

- **Localized Decarburization of Steel:** Carburising is also a significant factor in the development of tender areas. This is a frequent issue in pack carburising when the steel element is not correctly packed. This leads to soft nuclei as a consequence of the irregular distribution of carbon. The carburising layer is exceedingly thin, and excessive grinding may result in the exposure of soft areas, which in turn leads to the formation of soft regions [8].
- **Inhomogeneous Microstructures**
- **Improper handling during quenching**
- **Uneven heating:** Sometimes overly massive and heavy steel components are heated unevenly, causing soft spots in the steel when they are placed in a furnace.
  • The steel component was not properly cleaned.Cleaning carbon steel before heat treatment is essential. The presence of dirt areas and dust particles might hinder heat transmission into the steel, resulting in incorrect chilling of the steel element. As a result, steel's hardness distribution becomes uneven.

2.2 Lower hardness and strength after Quenching

For increased strength and hardness, carbon steel needs martensitic development. The cutting tool, powder metallurgy, and defence industries all often employ martensitic steels. To achieve the appropriate hardness and strength, these steel varieties go through a number of heat treatments. Failure to achieve the desired strength or hardness after heat treatment may be the cause.

The following are typical causes of steel's decreased stress and hardness following heat treatment:

- Lower **hardening temperature**

Achieving increased strength and stiffness requires martensitic production. If the austenitizing temperature is not adjusted properly, there is a chance that martensitic will not occur during quenching. To understand why the immersion temperature matters, see the article "Effect of Austenitizing Temperature on Quenching of Steel." The presence of entire homogeneous austenite at the incubation temperature must be confirmed prior to quenching. It is essential for building more resilience and endurance. Alloying elements can have a major impact on the austenitic temperature needed for homogenisation. For more details, please consult the following sources: "Study of the effect of alloying elements on steel, phase diagram, and TTT diagram[9].

- **Insufficient Soaking Time**

At soaking temperature, alloying elements impede homogenisation and reduce diffusion rate. As previously mentioned, full austenitic production at soaking temperature is necessary to achieve increased hardness and strength.

- **Delayed Quenching/Slower Cooling Rate**

Quenching is a crucial component. The diffusion-based transformation seen in the steel TTT diagram may begin with a modest drop in cooling temperature. As a result, pearlitic formation is produced, which is less hard than martensite. For steel to achieve greater hardness and strength, the cooling rate must be greater than the critical cooling rate[10].

- **Presence of large amount of retained austenite**

We spoke about how raising carbon may both raise the chance of martensitic formation and lower the Mf temperature line. A lower Mf leads to a higher retention of austenite because it reduces the martensitic transmutation from austenite. The addition of auxiliary components also increases the probability that a matrix will have a larger percentage of retained austenite. Tempering is essential for achieving greater hardness in microstructures that need to convert retained austenite.

- **Low Hardness in Surface Hardening Treatment**

Strength or hardness may occasionally be decreased as a result of carburising, nitriding, or cyaniding. This happens when there is not enough steel in a furnace to achieve a consistent temperature, or when there is not enough carburising material or heat treatment temperature, as explained in the article "Soft spot generation in steel[11].

2.3 Quench Cracks

Large structural components are severely cooled during the crucial phase of quenching, which results in the martensitic transition. Several tensile and compressive stresses related to the austenite to martensite transition are constantly present during this quenching process. In extreme situations, these tensions cause cracks during heat treatment and are considered heat treatment faults. Quench Cracks are cracks that form during the hardening process. fractures in these It is concerning because these fractures make steel useless and worthless as scrap [12].

2.4 Distortion & Warping

Warping and distortion are the most common problems with carbon steel and are difficult to totally eliminate, A symmetrical change in a component's size or form, as the contraction of a steel component during refrigeration, is referred to as distortion. Warping is the term used to describe asymmetrical transformation. For example, warping of steel is the term used to describe the distortion or loss of straightness of thin steel sheets as they cool [13]. Over the course of heat treating steel, the following structural changes will take place:

- The steel is heated to the AC1 line by thermal expansion.
- When the AC1 line is crossed, the transformation into austenite causes contraction.
- Austenite's thermal expansion as a result of further heating till homogenisation.

The steel component expands during the transformation process and again upon further chilling following a full transformation. • Thermal contraction, as previously described, occurs in quench cracks until Ms line for martensitic transformation or C-shape curve for diffusion-based transformation.

In the case of slow heating and cooling, steel will have enough time to experience a change in dimensions in order to relieve strains. Severe cooling will cause a non-uniform heat distribution in the sample, which will cause internal tensions to gradually emerge. These distortions might be the consequence of internal stresses created by the temperature differential between the steel's core and case, or they could be the result of residual tensions from martensitic development in steel [14]. After heat treatment, steel frequently exhibits one of two types of distortions:

1.Size Distortion

This deformity is the result of the expansion and contraction of steel during the heat treatment process.

2. Shape Distortion

Warping of steel is the word used to describe the bending and twisting of steel that causes this kind of deformation.

One of the most prevalent flaws in steel is distortion, which is frequently seen when the metal is heated. The original composition, design, starting condition, and machining techniques are the elements that should be optimised to reduce distortion.

2.5 Over Heating and Burning of carbon Steel

Due to its high strength, fatigue strength, and exceptional toughness, low alloy carbon steel hot work products are frequently utilised as machine tools and fasteners. Low alloy carbon steel that has been improperly hot worked loses its ductile qualities and develops faceted fracture surfaces, rendering it unsuitable for real-world uses. Usually, carbon steel overheating or burning results under these situations[15].

3. Results

Low carbon steel is a material that is extensively employed in a variety of industries due to its low cost and exceptional mechanical properties. Still, flaws such voids, inclusions, and fractures may reduce the strength and ductility of low carbon steel, therefore affecting its performance. One often used method for improving low carbon steel's mechanical qualities—including resilience and hardness—is heat treatment. Still, the inclusion of flaws in the heat treatment process might undermine its efficiency and result in less than ideal mechanical characteristics. Four low carbon steel samples were generated for the experimental work; Figure 1 shows this. Four separate heat treatments—quenching, normalizing, annealing, and tempering—were then carried out to look at low carbon steel's shortcomings. First we will characterize the flaws in the steel samples using non-destructive testing methods including ultrasonic testing and X-ray imaging. Following a range of thermal treatments—quenching, tempering, and annealing—we will next evaluate the mechanical characteristics of the steel samples—hardness, toughness, and ductility. We will compare the outcomes of the samples with and without flaws in order to assess the impact of flaws on the thermal treatment process. The findings of this work will help to create more efficient techniques to improve the mechanical qualities of low carbon steel with flaws and provide insightful analysis of the effects of defects on the thermal treatments of low carbon steel.

Practical part steps:

1- Four pieces of low-carbon carbon steel were prepared for heat treatment in the following four ways: (a) Heating (b) Cooling (c) Leveling off (d) Pressing

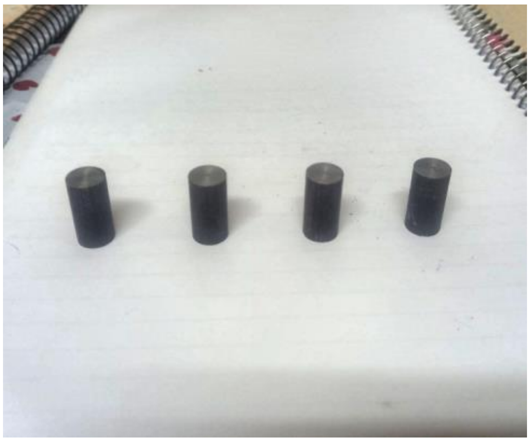

Fig.1: Prepared Four Samples for Testing

2- The furnace seen in fig 2 was used for heating the four samples. The furnace has been brought up to 280 degrees.

Fig.2 Furnace

3- The four samples have been put it in the oven for 20 minutes.

4- Then take it out and cool it in one of the following cooling media:

a. water.

b. air.

c. It was returned to the oven.

d. oil.

5- The hardness of each sample was examined by the Vickers hardness as shown in figure 3 and the partial composition of each of the four samples was known. Finally, microscopic tests for all the samples were done to detect the defects in each sample as shown in figure 4.

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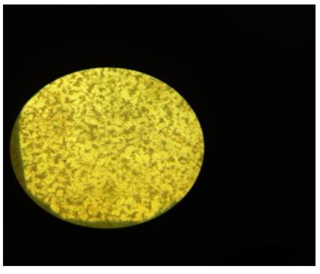
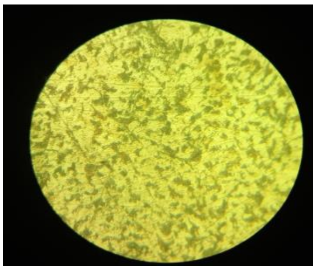
Fig.3 Hardness Tester

Fig.4 Microscope

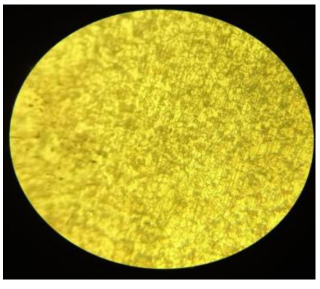
Galactic structures obtained from the samples as shown in figure 5



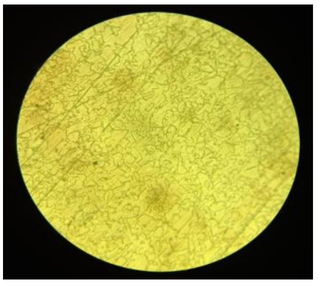
(a)Tempering



(b) annealing



(C) Quenching



(d) Normalizing

Conclusion

Analyzing heat treatment flaws in carbon steel is crucial for ensuring the mechanical performance and durability of the material in industrial applications. These flaws, often arising from improper heating, cooling rates, or inadequate process control, can significantly impact the steel's microstructure, leading to defects like uneven hardness, cracking, or distortion. Through comprehensive evaluation methods such as metallurgical analysis, hardness testing, and non-destructive testing techniques, the root causes of these flaws can be identified and mitigated. Proper standardization of heat treatment parameters, including temperature control and cooling medium selection, is essential to achieve desired material properties. Advanced simulation tools and real-time monitoring can further enhance process reliability and reduce errors[16]. Addressing heat treatment flaws not only improves the quality of carbon steel but also extends its lifespan and reduces maintenance costs. Effective training of personnel and adherence to industry standards play a pivotal role in minimizing defects. This analysis underscores the importance of precision and vigilance in heat treatment processes to meet the requirements of critical engineering applications.

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