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Comparison of a Medium Carbon Steel Microscopic and Hardness Properties Following Different Heat-Treatments

Hasan Mahmood Kaedhi, Luqman Khaleel Hyder Alatrushi, Emad Toma Karash*, Mohammad Takey Elias Kassim, Jamal Nayief Sultan

Mechanical Technology Department, Mosul Technical Institute, Northern Technical University, Mosul 41000, Iraq

Corresponding Author Email: emadbane2007@ntu.edu.iq

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ABSTRACT

This article investigates how medium carbon steel's microstructure and hardening strength are affected by repeated heat treatment. Finding out the impact of repeatedly heat-treating medium carbon steel is the primary goal of this investigation. In this study, four different heat treatment techniques were used: first quenching, first tempering, second quenching, and second tempering. During the first quenching process, the samples were heated at 870℃ and left in the oven for 45 minutes. The samples were then quenched in distilled water at different temperatures (0, 5, 10, 15, 20℃). The first tempering step, which lasted 25 minutes at 350℃, came after the first quenching step. The samples were heated to 850℃ and placed in the oven for 45 minutes in order to undergo the second quenching process. After that, the samples were quenched at various temperatures (0, 10, 20, and 30℃) in a medium containing distilled water. The second tempering procedure came after the second quenching step, which lasted 25 minutes at 450℃. All samples underwent microscopic inspections and hardness tests following the various heat treatment processes. Each sample's five surface areas underwent hardness testing and microscopy, and the results were compared and analyzed. Research has shown that the steel has undergone various heat treatment procedures, resulting in varying microstructure and hardness values. The hardness of the models that underwent repeated hardening procedures has been shown to significantly increase. In addition, the specimens obtained after the first and second quenching and tempering exhibit a good combination of mechanical properties due to their microstructure. This is because the specimens become more ductile and tough as a result of the quenching and tempering processes, which decrease fragility.

1. INTRODUCTION

In order to modify the physical and mechanical properties of engineering materials mostly steel under a carefully regulated heating and cooling cycle, the materials are heat treated. The most prevalent type of steel is medium carbon steel. Owing to its comparatively low cost and exceptional mechanical attributes, like elevated strength and resilience, over many metals, it finds widespread use in engineering applications. A lot of buildings and bridges are constructed using medium carbon steel. This metal is also used for railroad tracks, pressure vessels, and ships. It is also used to make diesel pump injection parts and parts for automatic filling machines. Two-phase steels are commonly defined as steels that contain a combination of martensite and ferrite. To improve its mechanical properties, medium-carbon steel is heated through the processes of austenitization, quenching, and hardening. Strength versus cost is the basis for this. Medium-carbon steel is distinguished by its exceptional capacity to support a wide range of loads. These steel heat treatments have been the subject of numerous studies by researchers looking to enhance different mechanical properties [1-5]. The term "heat treatment" refers to a process that combines heating and cooling procedures for different metals and alloys. The goal of this process is to produce the desired mechanical properties by controlling the product's shape over time while also keeping an eye on its microstructure. Enhancing the mechanical qualities of the metals and metal alloys that undergo these processes is the primary objective of heat treatment. In essence, when these procedures are carried out and the material's strength rises, the product's performance will improve. Annealing, quenching, and tempering are the three primary steps in heat treatment procedures. Additionally, the heat treatment procedure is typically completed in three stages. The material must first be heated; then, it must be kept at a specific temperature for a while; and finally, the metal or alloy must be cooled to room temperature using a designated cooling medium, such as water, oil, or air, for example [6-10]. This study examined the impact of the temperature at which plastic is tempered and the number of tempering cycles on the plastic's hardness, microstructure, and corrosion resistance. The obtained results indicated that the elongation was (11.4%) and the maximum tensile strength was (UST, 1441 MPa). Other findings show that samples that were hardened at 400℃

had the lowest corrosion rate (0.61 mg/g) [11]. The structural alterations that occur when martensite is tempered at high temperatures are more significant than when tempering at low temperatures. The process leads to a markedly reduced hardness as possible transition carbides dissolve first and are subsequently replaced by coarser cementite particles along with concurrently lower dislocation densities [12-14]. It is possible for carbides to form in the alloy [15], which causes secondary hardening. At high temperatures, traditional low to medium carbon RAQ martensite has been found to have a notable improvement in durability [16]. But research has shown that tempering has a complicated impact on the hardness of HTT directly quenched steel. This article studied how heat treatment affects the mechanical and microscopic properties of carbon steel. In addition to the microstructure of the heat-treated samples having finer granular structures compared to the original samples, the study demonstrated that the mechanical specifications of the heat-treated samples were improved over the original specimen [17]. In this article, different mechanical properties and microstructure modifications were examined using samples of steel alloys. The study's findings showed that the annealed samples with a predominantly ferrite structure had the highest values for ductility and toughness and the lowest values for tensile strength and hardness. On the other hand, the martensite-containing annealed sample had the lowest values for ductility and toughness and the highest values for hardness and tensile strength. [18]. This article studied how the microstructure and a few mechanical characteristics of the steel alloy were affected by heat treatment, including annealing, normalization, hardening, and tempering. The outcomes demonstrated that after heat treatments, steel's mechanical qualities considerably improved. Additionally, it was discovered that annealed samples with a martensite-dominated structure produced higher values than annealed samples with a primarily ferrite structure, which produced lower values [19]. The influence of heat treatment on the characteristics of rolled medium carbon steel was the main focus of this investigation. The findings demonstrated the exceptional combination of tensile strength, resistance of hardness, and an impact strength possessed by this newly developed metal, which is critical for structural applications across a wide range of industries [20]. This article reviews additional related heat treatments that are used as pre-treatments for specification, such as annealing and special treatments for property changes. which demonstrated a notable improvement in the medium carbon steel's mechanical specifications [21]. In this research, samples of mild steel were chosen so that both their microstructure and mechanical characteristics could be examined. The study's findings demonstrated that applying particular treatments for a given application in a given field can greatly enhance the mechanical properties of mild steel [22]. Results of this study demonstrated that samples quenched and cooled in 10% salty ice water, showed improvements of in tensile strength, hardness, microstructure, and corrosion resistance [23]. Quenching and partitioning (Q&P) steels are able to provide the necessary high strength and hardness when it comes to martensitic steels [24]. It is desirable to increase the steel's spot hardening capacity and hardness [25]. The transformation-induced plasticity (TRIP) phenomenon can easily produce ductility when there is a suitable fraction of fine austenite distributed among the martensite segments in Q&P steel [26]. According to additional research, brittleness in hard enamel or martensitic matrix can be mitigated by adding RA, which is helpful in extending the service life of equipment subjected to high speeds and high shock loads [27]. Several studies have been carried out to emphasize that one of the crucial engineering materials that can undergo heat treatment is medium carbon steel. This is because the heat treatment of this metal can yield notable modifications in its crystalline structure, which can lead to important improvements in its mechanical properties. The process of heat-treating medium carbon steel modifies its microstructure to accommodate different engineering uses and yields the mechanical characteristics needed for the intended application [28-31].

The purpose of this study is to determine the strength of hardness and microstructures of medium carbon steel specimens that will undergo repeated heat treatments. These procedures involve first quenching the specimens, cooling them with distilled water at different temperatures, and then tempering a preliminary evaluation of the specimens to enhance their internal structure. Subsequently, left some of the specimens alone and proceeded to quenching the remaining ones again. then cooled the specimens in distilled water at varying temperatures and conducted another tempering of them. After that, it will be investigated how these processes affect the microstructure's structure and hardness strength. Then, we make a comparison and contrast all the outcomes with the original specimens which had not undergone any heat treatments. The goal is to identify the optimal specimens and distilled water temperatures that produce the best outcomes.

2. MATERIALS AND METHODS

2.1 Materials

A medium carbon steel with acceptable mechanical properties that can be heat treated is AISI 1040 steel. The standard chemical component values and the metal value used in this study are displayed in Table 1 [32, 33].

Table 1. Chemical composite of AISI 1040 steel

Element (wt. %)	Standard Value [33]	Actual Value
Fe	98.6 - 99	98.773
Mn	0.6 – 0.9	0.732
C	0.37 – 0.44	0.421
S	≤ 0.05	0.041
P	≤ 0.04	0.033

2.2 Classify specimens into groups

The specimens were separated into the following six groups:

The first group consists of the undivided specimens (B1, B2, B3).

The second group consists of the specimens (1, 6, 11, 16, 21, 26). The first step involves first quenching, followed by cooling with distilled water at varying temperatures (0, 5, 10, 15, 20, 25℃), then first tempering.

The third group consists of the specimens (2, 7, 12, 17, 22, 27). The first step involves first quenching, followed by cooling with distilled water at varying temperatures (0, 5, 10, 15, 20, 25℃, respectively), and first tempering. The second step involves a second quenching, which involves cooling with distilled water at 0℃, then second tempering.

The fourth group: includes specimens (3, 8, 13, 18, 23, 28), the first stage: first quenching and cooling with distilled water at different temperatures (0, 5, 10, 15, 20, 25°C) respectively - and first tempering. The second stage: second quenching - cooling with distilled water at temperature (10°C) - and a second tempering.

The specimens in the fifth group are (4, 9, 14, 19, 24, 29). The first step involves first quenching and cooling with distilled water at varying temperatures (0, 5, 10, 15, 20, 25°C), then first tempering. The second step consists of a second quenching, which involves cooling with distilled water at 20°C and second tempering.

The sixth group consists of the following specimens: (5, 10, 15, 20, 25, 30), the first step is first quenching, followed by cooling with distilled water at different temperatures (0, 5, 10, 15, 20, 25°C, respectively), and first tempering. The second step involves a second quenching, which involves cooling with distilled water at 30°C and second tempering.

2.3 Heat treatment process

Following the process of quenching and cooling the specimens, the martensite becomes extremely brittle. This brittleness is primarily caused by the predominance of martensite, which can be eliminated through tempering. The desired combination of mechanical specifications (hardness, ductility, durability, strength, and structural stability) is achieved through hardening.

In the first step: The groups (2, 3, 4, 5, 6) underwent the first quenching process by being placed in an oven set at 870°C, for 45 minutes. Afterward, they were removed from the oven and cooled in distilled water at different temperatures (0, 5, 10, 15, 20°C), depending on the group's order. The initial tempering procedure was then completed. The samples for each of the five groups' specimens were heated to 350°C for 25 minutes, after which they were allowed to cool in the oven.

During the second stage: The groups (3, 4, 5, 6) were subjected to a second quenching procedure wherein they were baked at 850°C for 45 minutes. Then, in accordance with the order of the groups, they were removed from the oven and cooled in distilled water at different temperatures (0, 10, 20, and 30°C). Following that, the second tempering procedure for the four-group specimens was completed by heating the oven to 450°C for 25 minutes, putting the specimens in the oven for twenty minutes, and then allowing the oven to cool down.

2.4 Microscopic analysis

The microstructure of the samples used in this study was examined and analyzed using a microscope. This is related to clean and polished surfaces of the samples in order to obtain a clear microscopic structure and the possibility of studying the type of grains of the metal to be studied. Different grades (80, 220, 320, 600, 1000, 1500, 2000) of polishing paper were used to prepare the surfaces of the samples.

The extremely smooth surfaces were then achieved by cleaning the polished surfaces with a damp cloth and alumina (Al_2O_3) and magnesia (MgO). After that, the surface was treated with Nital exposure solution, which is unique to the kind of metal employed in this study and is composed of 98% CH_4 and 2% HNO_3, to highlight the microscopic structure of the models that were examined under a microscope.

2.5 Hardness check

The Vickers hardness test was utilized in this study due to its user-friendliness and ability to be applied to all metal types, regardless of their hardness. A micro hardness tester was employed. The hardness was tested using an Indenter tool shaped like a quadrilateral diamond pyramid that was angled at a 136°and weighed 0.5 kg.

Polishing paper of varying degrees was used to prepare the research samples whose hardness was to be measured. This ensured a smooth, imperfect-free surface. To guarantee that the load applied in the device was applied vertically and to achieve high accuracy in the readings, a clean surface was prepared for the samples on both sides.

Accurate Vickers hardness readings were obtained by computing the Vickers hardness of every sample used in the study.

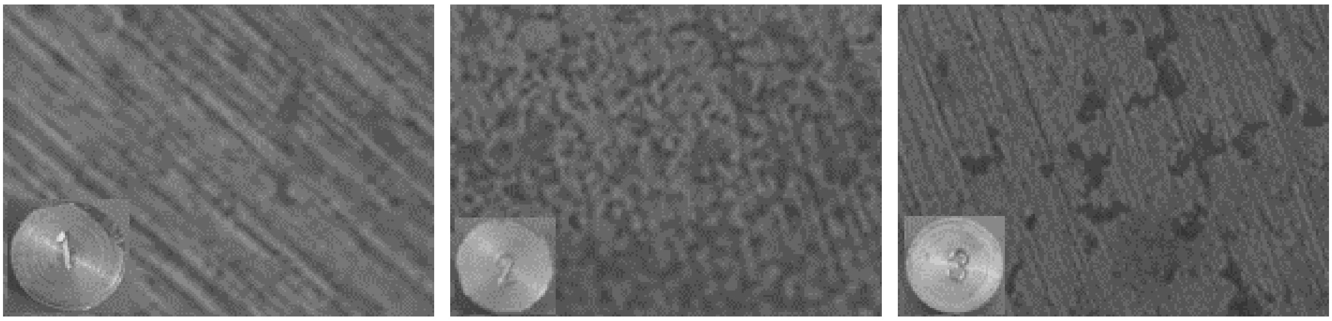
3. RESULTS AND DISCUSSION

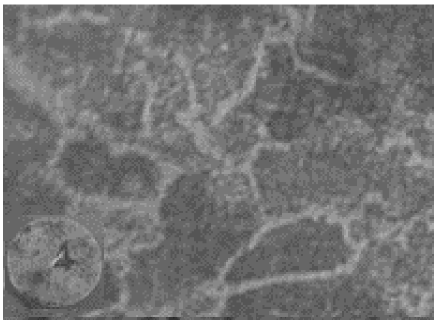
3.1 Microstructural results

Figure 1 shows the microscopic structure of the samples prior to heat treatment. Some samples were quenched once and cooled in distilled water at different temperatures; these samples were then tempered for the first time; other samples were quenched twice and cooled in distilled water at different temperatures before being tempered again.

3.2 Hardness results

A comparison between all groups' hardness resistance and the original model is displayed in Figures 2-7. The models' hardness resistance increases and decreases as a result of different heat treatments, as seen in the figures. The microscopic structure of the samples in Figure 1 illustrates the reason for this, which is the variation in the crystalline structure of the different samples after different heat-treated.

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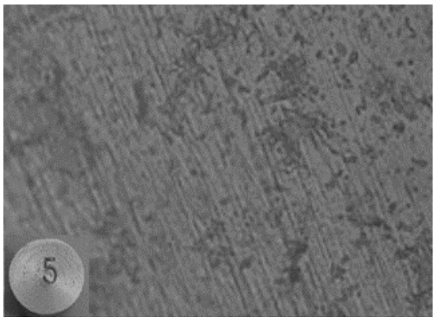
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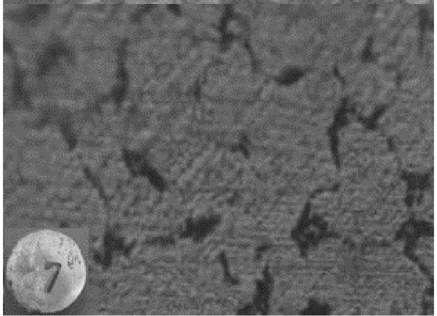
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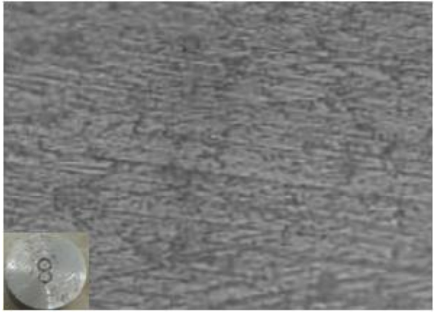
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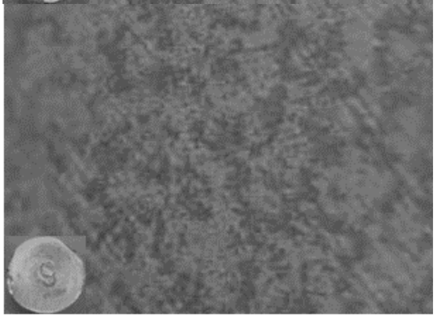
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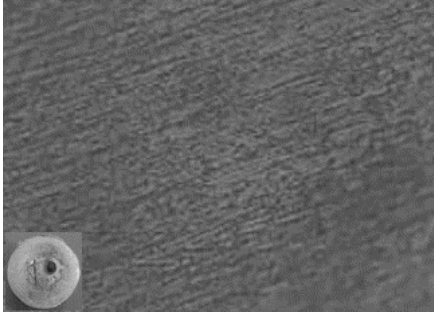
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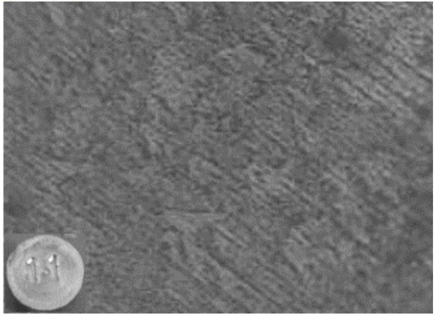
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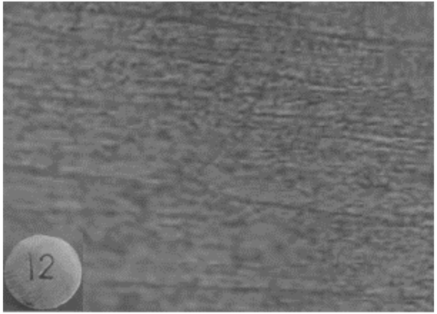
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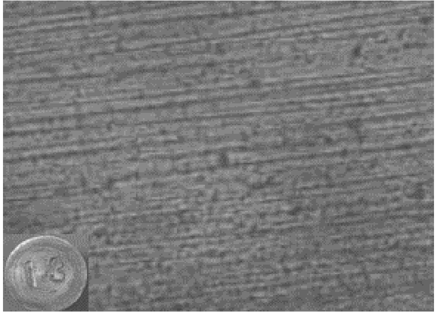
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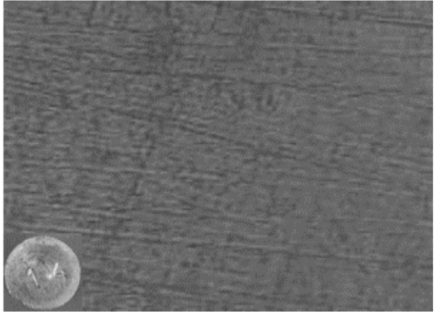
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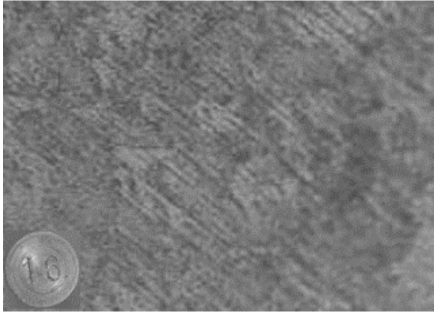
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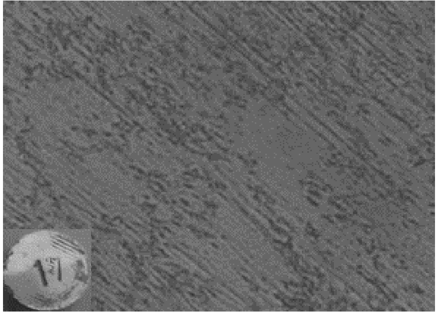
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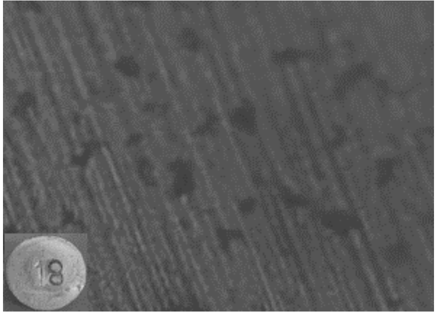
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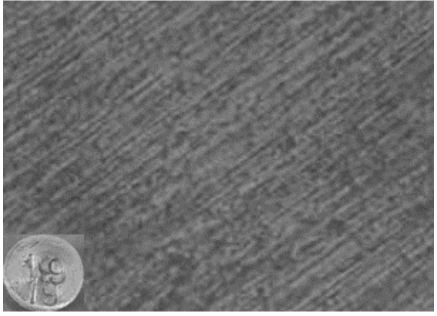
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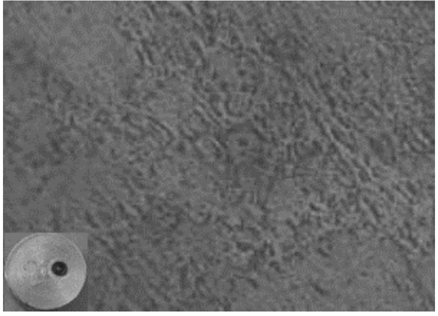
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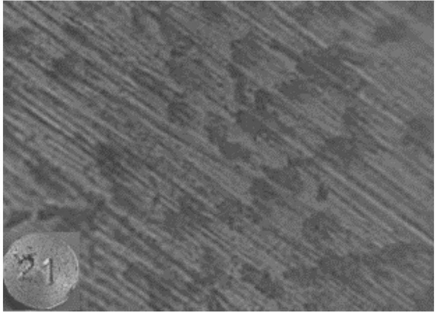
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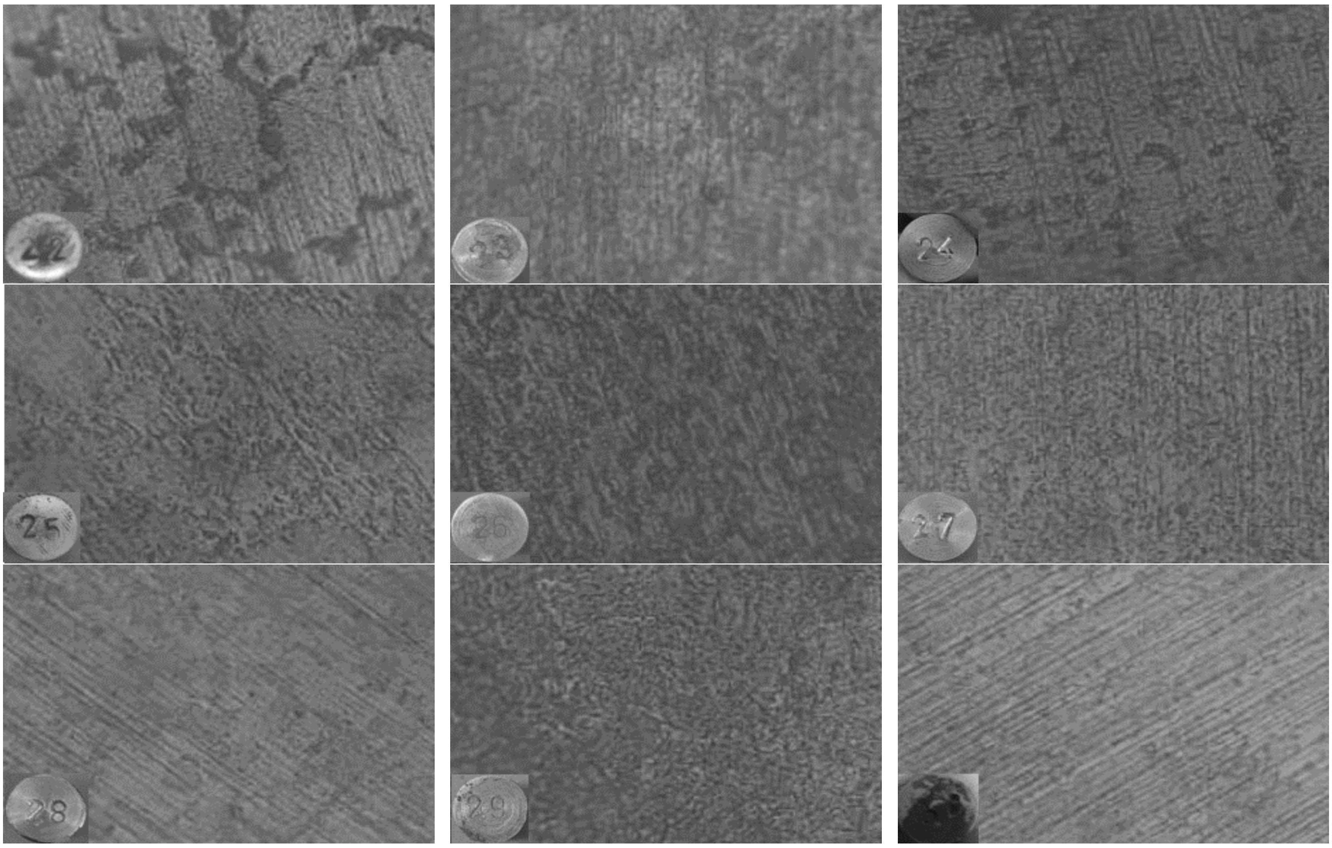

Figure 1. The samples' microscopic structure before they are heated

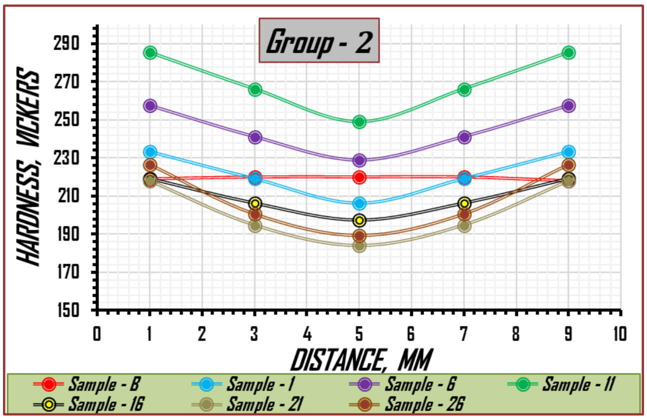

Figure 2. A comparison of all models group – 2, that have been heat-treated with the original model

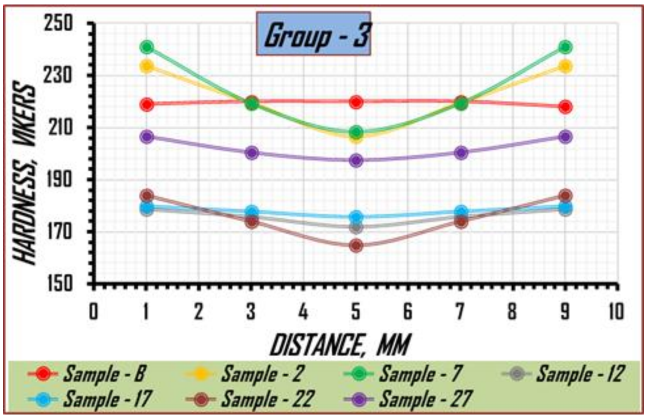

Figure 3. A comparison of all models group – 3, that have been heat-treated with the original model

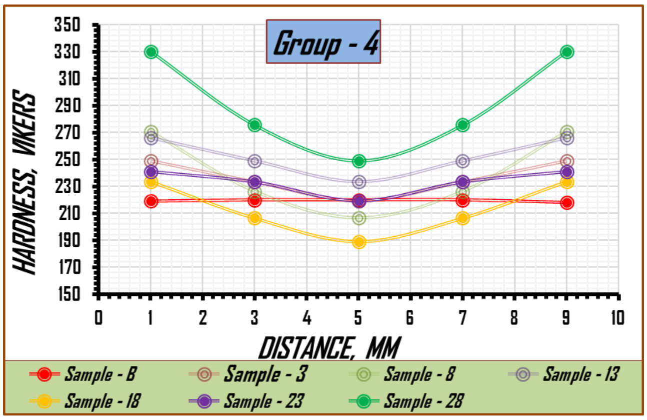

Figure 4. A comparison of all models group – 4, that have been heat-treated with the original model

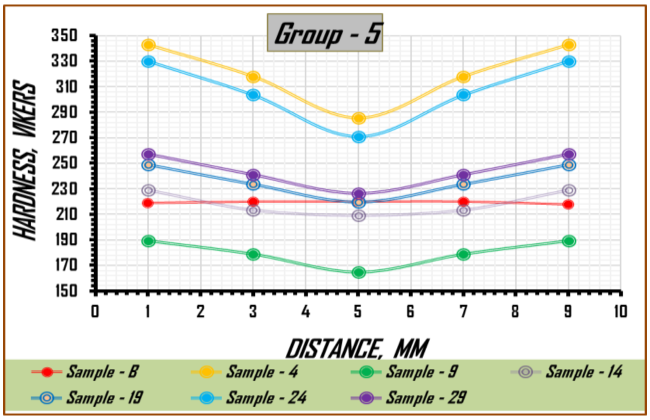

Figure 5. A comparison of all models group – 5, that have been heat-treated with the original model

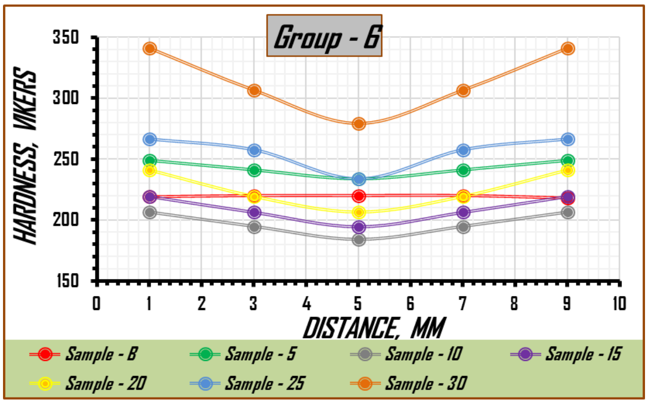

Figure 6. A comparison of all models group – 6, that have been heat-treated with the original model

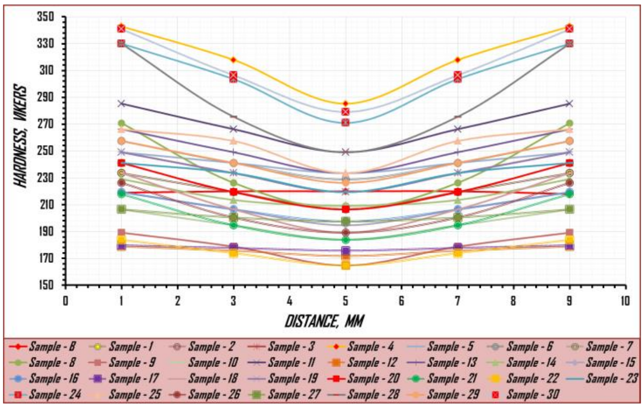

Figure 7. A comparison of all models that have been heat-treated with the original model

4. CONCLUSIONS

The present investigation concludes that the experimental study was successful in accomplishing its intended objective, which involved subjecting medium-carbon steel to repeated heat treatment at varying temperatures while it was cooled in distilled water. The microstructure of medium-carbon steel was examined under a metallurgical microscope, and the findings indicated that the sample plasticizers with a primarily ferrite composition had the highest ductility and hardness values, but the lowest hardness value. But after cooling, martensite formation is visible in the microstructure. This martensite sample is extremely brittle, demonstrating an increase in hardness that makes it unsuitable for any kind of application. To improve the martensite's ductility and hardness, tempering is then required. The microstructure changed from martensite to hardened martensite and recrystallized ferrite grains were discovered after the first quenching at a high temperature of 870℃ and the first tempering at a temperature 350℃, as well as after the second quenching at a temperature 850℃ and a second tempering 450℃ at a temperature. In light of the results, the hardness value at different temperatures after cooling in distilled water exhibits higher hardness in varying percentages, but it may also be lower, albeit in extremely small percentages. This is due to the fact that water cools quickly, making it the ideal medium for cooling processing. On the other hand, when the sample is tempered at different temperatures, the hardness varies. This outcome shows that a good combination of mechanical properties can be obtained from the microstructure that is left over after tempering. Furthermore, the grain size decreases with increasing quenching cooling rate. Steel will become harder as a result. The strength of the steel will increase but its hardness and ductility will decrease if the cooling rate is too high. Steel typically becomes more brittle and less malleable at high cooling rates.

5. RECOMMENDATIONS AND FUTURE WORKS

The following suggestions for more investigation and useful applications can be made in light of the comparative analysis of the hardness and microstructural characteristics of medium carbon steels following various heat treatments:

1. Examine the microstructural alterations that medium carbon steels undergo through heat treatment in great detail. In order to examine the evolution of grain structure, dislocation density, and other microscopic features, sophisticated microscopic techniques like electron and X-ray diffraction may be employed.
2. Investigate methods for enhancing medium carbon steels' mechanical qualities in accordance with the needed use. Examine how the strength, hardness, ductility, and toughness of the material are affected by various heat treatment parameters, such as the deformation temperature, strain rate, and degree of deformation.

It is possible to advance knowledge and applications of heat-treated medium carbon steels by taking these suggestions into consideration. The design of high-performance components made with medium carbon steels will benefit from this knowledge as it will help various industries develop better processing methods.

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