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Impact Load Resistance of Steel after Heat Treatment and Quenching with Distilled Water

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ABSTRACT: Given that low carbon steels have favourable mechanical properties, they are widely used in power plant components, oil and gas pipelines, and armor structures. However, the relationship between a steel's structure and mechanical properties can occasionally be negatively impacted by the existence of ferrite and pearlite phases in its microstructure. One of the most crucial aspects of engineering metallurgy is the heat treatment of steels, which improves a variety of mechanical and physical characteristics that are useful in many structural applications. The heating and cooling of an alloy or metal while it is solid in order to refine its grain size and other properties and create the necessary microstructures is known as heat treatment.

This paper will use distilled water as a cooling medium at various temperatures to perform repeated heat treatments. Comparing the impact load resistance of the original and treated specimens is the goal, as is the impact of multiple heat treatments and the use of distilled water as a medium for cooling at different temperatures. The findings of an Excel program study show that the heat-treated samples had a greater impact resistance value than the untreated ones. The strong martensitic network alloys created by heat treatment procedures are the main factor contributing to the increase in impact load resistance. The average pendulum angle values of the six heat-treated compounds were found to have a higher elevation angle than the average values of the original group. There was the least amount of decrease from the average value of the second group, which was 0.93 %. The average toughness values of the six heat-treated groups increased in comparison to the original group's average values, with the second group experiencing the largest percentage increase (11.96%). Based on the difference in coolant temperatures, the group that was cooled in distilled water at zero temperature had the best toughness value.

KEYWORDS: Impact Resistance, Repeated Heat Treatment, Quenching, Structures, Low Carbon Steel.

I. INTRODUCTION

Steels are the most practical of all materials and are well known for having many desired qualities that may be altered by changing their microstructure and chemical makeup, as well as their relatively low cost. Steel plates and bars used in construction, line pipe, automobiles, pressure vessels, naval, and defense applications must have an exceptional blend of high strength and high toughness depending on their mechanical characteristics.

[1-5]. The creation of such high-performance steels has been made possible by developments in our knowledge of how the microstructure's shape and behavior might impact its mechanical qualities. In order to design the microstructures for particular applications, phase transformations are therefore essential. The superior ductility, weldability, and formability of low-carbon and low-alloy steels over other steel grades are advantageous when taking into account the aforementioned applications [6-10]. Low-carbon high-strength steel's special mechanical qualities and weldability have made it useful in a variety of industries, including railroads, cars, mining equipment, and shipbuilding [11]. However, manufacturing large-scale fabrications with complex structures using traditional methods is challenging, expensive, and time-consuming. As a promising technology, additive manufacturing (AM) might be a better option when dealing with these issues [12]. ASTM A216WCB and other low-carbon steels are especially well-suited for Utilize in high-temperature components of services that can be created or fixed using fusion welding methods. The component frequently needs to be repaired because of the way ASTM A216WCB is used. This can be accomplished by replacing the parent material lost due to erosion procedures. in elbows, and valves by employing techniques such as metal active gas welding. High temperatures will be experienced in the heat-affected zone (HAZ) around the weld site during the welding process. Microstructural alterations could occur if these temperatures increase above the lower critical temperature (&723 C). Furthermore, as cooling occurs, the base material receives comparable compressive forces while the weld material experiences tensile stresses [13-17]. In order to achieve wanted material properties (such as impact, fatigue, corrosion, electrical, magnetic, etc.), heat treatment entails applying heat to the material. The material typically experiences phase microstructural and crystallographic changes during the heat treatment process [18]. Carbon steel is heat treated to alter its mechanical characteristics, most commonly its mechanical

properties. During the heat treatment process, there are also minor changes in electrical, corrosion, and thermal conductivity. Based on their yield strength. Yield strength is the basis for the majority of engineering calculations for structure [19]. Water cooling and thorough heat treatment are necessary to attain the required qualities. Any heat treatment or other thermal process that introduces third phases or moves the alloy too far from the nominal phase equilibrium may cause corrosion resistance, decreased mechanical properties, or both. It should be acknowledged that improper handling of these grades can have serious consequences for safety and cost, and that repairs can be extremely challenging [20, 21]. Because of this, several large users have implemented a very stringent manufacturer eligibility process in an effort to guarantee a high-quality product [22, 23]. [24] In this paper studying the impact properties and hardness of medium carbon steel treated with various heat treatment techniques is the primary goal of this project. Three different forms of heat treatment annealing, quenching, and annealing were used in this project. Following quenching and annealing, the samples' results from the Charpy impact test and the Rockwell hardness test were compared and examined based on the findings of this investigation. It was noted that the steel's hardness and impact properties varied depending on the heat treatment method, and that as the annealing temperature rose, the steel's hardness rose in tandem with the absorbed energy. [25] This experimental study examined the impact resistance load of heat treatment on low carbon steel and determined the microstructure and hardness number of steel samples. To put it briefly, hardening yielded a higher hardness number than annealing and normalizing. This resulted from martensite formation, which hardened the steel. [26] This study studies how heat treatment affects the mechanical and microstructural characteristics of low carbon steel. The heat-treated sample was the hardest and impact resistance value of energy of 65.43 J. The hardened sample displayed the highest Brinell hardness number, 434 BHN. [27] In this study, the alloy steel specimens EN 31, EN 24, and EN 8 were chosen to test various mechanical characteristics and microstructure variations. The findings demonstrated that various heat treatments can modify and enhance mild steel's mechanical qualities for a given application. It was discovered that the hardened specimen made of martensite gave the highest tensile strength and hardness values and the lowest tensile strength and hardness values, while the annealed specimens with primarily ferrite structure gave the lowest and the highest figures. [28] This study examined how heat treatment affected the mechanical characteristics of steel welded joints. When heat-treated ASTM A36 welded joints are quenched in air, an oven, water, or spent engine oil, their impact energy (IE) and impact strength (IS) also significantly rise. [29] Water quenched medium carbon steel's hardness and impact strength were examined in relation to water temperature. Using water at temperatures ranging. Impact strength was increased by more than 50% and hardness was decreased by more than 18%, according to the results. By substituting tempered martensite structures for the hard structure of martensite that typically renders quenched steels extremely was brittle and also low in toughness, the steel's mechanical qualities improved. [30] The authors' study provides compelling evidence for experimenting with a blend of biodegradable oils as extinguishing agents and examining the impact of metal salts as extinguishing accelerators. The study's findings demonstrated that heat-treated samples had higher hardness and impact strength values than untreated samples, and that they also experienced reduced weight loss from abrasion.

In this article, six sets of low carbon steel will undergo heat treatments at varying temperatures utilizing distilled water as a quenching medium. In order to determine the optimal impact load resistance for the ideal distilled water quenching temperature, the impact load resistance of the original and treated samples will be compared with the effects of heat treatments and distilled water quenching medium at various temperatures.

II. MATERIALS AND EXPERIMENTAL PROCEDURE

II.1. Materials

The German standard (DIN) was compared to low carbon steel samples utilized in this investigation. Illustration 1. Both the chemical structure of the used samples and the usual standard chemical structure are displayed.

Table 1: Shown both the typical standard chemical structure and the chemical structure of the utilized samples

Wt., %,	C,	Si,	Mn,	P,	S,	Mo,	Cu,	Fe,
Standard value	0.16 – 0.29	0.15 - 0.35	0.5 - 0.8	≤ 0.035	≤ 0.035	-----	-----	Rem
Actual value	0.282	0.221	0.562	0.011	0.033	0.079	0.015	98.797

II.2. Method of Experimentation

Sample preparation and heat treatments These alloys are heated and cooled in a procedure called "heat treatment of alloy steel." The main objective of heat treatments is to improve the properties of steel, especially its resistance to impact. In this work, thirty-three carbon steel samples that met the testing equipment's size and form requirements were used to examine the impact resistance behavior of heat-treated and cooled samples in distilled water at different temperatures. The thirty-three samples were divided into five groups for repeated heat treatments, and their classification is shown in Table 2

Table 2: Classification of low carbon steel samples used in impact tests

solution heat treatment	(Quenching = 870 °C & 45 min.) (Tempering = 350 °C & 25 min.)		
	Specimens No.		
As received	M		
Water (0°)	M1	Water (15°)	M16
	M2		M17
	M3		M18
	M4		M19
	M5		M20
Water (5°)	M6	Water (20°)	M21
	M7		M22
	M8		M23
	M9		M24
	M10		M25
Water (10°)	M11	Water (25°)	M26
	M12		M27
	M13		M28
	M14		M29
	M15		M30

II-3. Impact test

These tests are used to determine a material's toughness based on its capacity. The Charpy Impact test uses a standard notched test piece that is supported at both ends to withstand mechanical shock. After being released, a heavy pendulum on ball beams is permitted to strike the test piece. The test piece breaks partially as a result of the striking energy being absorbed from fixed height. The test piece is notched to create stress concentration to guarantee that the fracture does occur, and the appointer is dragged by the pendulum to show the fracture energy.

The figure displays the same test specimen for both the ISO Charpy V - Notch and ASTM E23 Charpy impact test patterns.

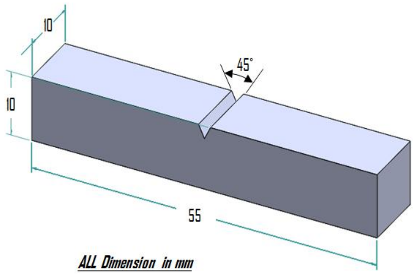

Figure 2. ASTM E23 Charpy impact test specimen

II-3-1. Calculation of Charpy Impact test

It is necessary to measure the energy absorbed to shatter the specimen in impact tests. The test specimen will shatter when the pendulum is withdrawn, and the pendulum will then swing back; the more energy absorbed, the less the swing back from the pendulum. The calibrated pointing scale on the testing apparatus often provides a direct reading of the absorbed energy. Another way to express absorbed energy is as a formula [30 – 33]:

1. Calculate Energy (W)

$$\boldsymbol{W = m \cdot g \cdot R \cdot (Cos\,\beta - Cos\alpha)}$$

W: $Energy, (N.m)$
m: $Weight,$ (Kg)
g: $Gravitational\ Acceleration, (\frac{m^2}{s})$
R: $Pendulum\ length, (m)$
β: $Angle\ of\ incidence\ of\ the\ pendulum, (Degree)$
α: $Angle\ of\ elevation\ of\ the\ pendulum, (Degree)$

2. Calculate Toughness (T)

$$\boldsymbol{Toughness\ (T) = \frac{Energy\ (W)}{Area\ (A)}}$$

T: $Toughness\ , (Kg.m/cm^2)$
A: $Area\ , (cm^2)$

III. RESULTS AND DISCUSSION

Findings for the initial model and models that underwent heat treatment and cooling in distilled water at different temperatures, and then put through the tempering process are displayed in Table 3 and Figures 2, 3, and 4. Table 4 shows the results of the impact resistance, toughness, and pendulum's rate of angle of elevation for each of the six groups with the original model.

Table 3: Result of the impact tests

solution heat treatment	(Quenching = 870 °C & 45 min.) (Tempering = 350 °C & 25 min.)				
	Specimens No.	Impact			
		Angle α°	*Angle β°*	Impact (J)	Toughness (KJ/ m²)
As received	**M1**	2.674	141.5	**1885.8**	**23.572**
	M2	2.677	141.5	**1855.4**	**23.192**
	M3	2.676	141.5	**1868.5**	**23.356**
Water (0°)	**M1**	2.642	141.5	21.608	27.009
	M2	2.651	141.5	20.867	26.084
	M3	2.645	141.5	21.360	26.700
	M4	2.657	141.5	20.270	25.338
	M5	2.654	141.5	20.577	25.721
Water (5°)	**M6**	2.656	141.5	20.365	25.456
	M7	2.660	141.5	20.002	25.003
	M8	2.654	141.5	20.548	25.684
	M9	2.649	141.5	21.057	26.321
	M10	2.658	141.5	20.241	25.301
Water (10°)	**M11**	2.667	141.5	19.402	24.253
	M12	2.661	141.5	19.981	24.977
	M13	2.660	141.5	20.052	25.065
	M14	2.652	141.5	20.739	25.923
	M15	2.666	141.5	19.544	24.430
Water (15°)	**M16**	2.665	141.5	19.619	24.524
	M17	2.646	141.5	21.270	26.587
	M18	2.658	141.5	20.240	25.300
	M19	2.666	141.5	19.498	24.372
	M20	2.658	141.5	20.202	25.252
Water (20°)	**M21**	2.654	141.5	20.563	25.703
	M22	2.656	141.5	20.422	25.527
	M23	2.656	141.5	20.420	25.525
	M24	2.663	141.5	19.783	24.728
	M25	2.660	141.5	20.078	25.097
Water (25°)	**M26**	2.656	141.5	20.410	25.512
	M27	2.660	141.5	20.080	25.100
	M28	2.656	141.5	20.373	25.466
	M29	2.656	141.5	20.414	25.517
	M30	2.652	141.5	20.728	25.910

Table 4: Average of result of the impact tests

Type of solution heat treatment	(Quenching = 870 °C & 45 min.) (Tempering = 350 °C & 25 min.)				
	Specimens No.	Impact			
		Angle of elevation of the pendulum α°	*Angle of incidence of the pendulum β°*	Impact (J)	Toughness (KJ/ m²)
As received	**Group - 1**	2.675	141.5	18.699	23.373
Water, (0°)	**Group - 2**	2.650	141.5	20.936	26.171
Water, (5°)	**Group - 3**	2.655	141.5	20.443	25.553
Water, (10°)	**Group - 4**	2.661	141.5	19.944	24.929
Water, (15°)	**Group - 5**	2.659	141.5	20.166	25.207
Water, (20°)	**Group - 6**	2.658	141.5	20.253	25.316
Water, (25°)	**Group - 7**	2.656	141.5	20.401	25.501

Figure 2 shows the average values of the pendulum's angles of elevation for each of the seven groups both before and after the thermal treatments. It is evident that, in comparison to the average of the initial set of models, the values of the pendulum's angles of elevation for the models that underwent heat treatment and cooling in distilled water at various temperatures dropped. The average value of the second group, which was reported as having the lowest value, is 2.650.

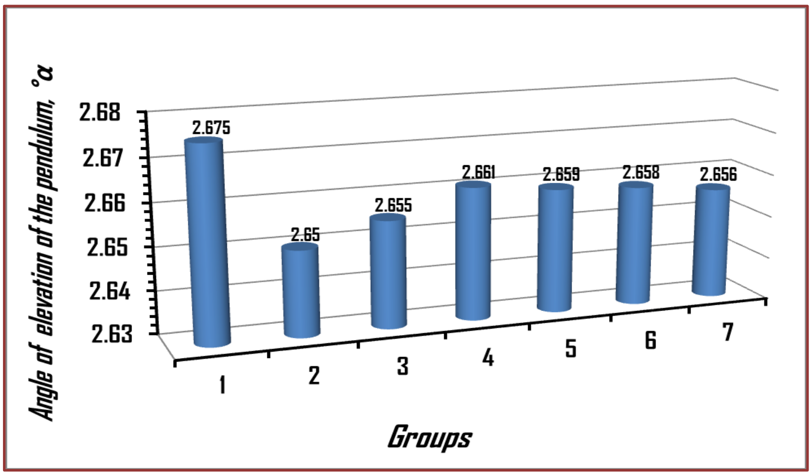

Figure 2: Result of the Angle of elevation of the pendulum (α°)

Figure 3 presents the average values of the impact strength for each of the seven groups both before and after the thermal treatments. It is evident that, in comparison to the average of the original group of models, the impact strength results for the models that had heat treatment and cooling in distilled water at various temperatures increased. The impact strength value of 20.836 J was the heights value found in the average values of the second group

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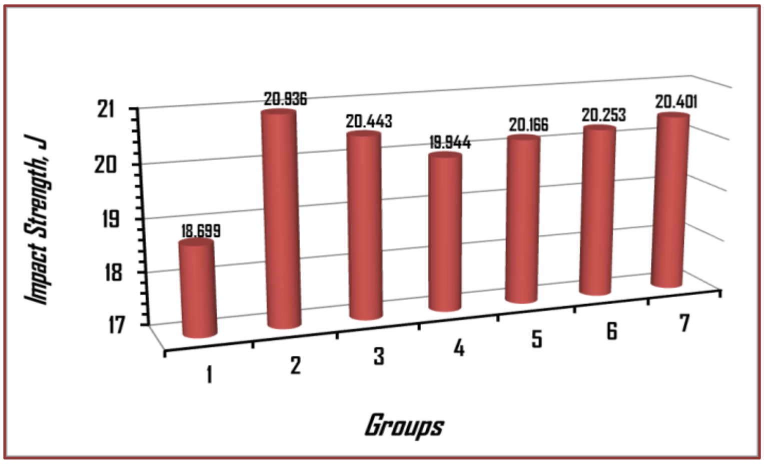

Figure 3: Result of Impact strength, Joule

Figure 4 displays the average Toughness values for each of the seven groups both before and after the heat treatments. It is evident that the models that underwent heat treatment and cooling in distilled water at varying temperatures had higher Toughness results than the average of the original group of models. The average results of the second group had the highest Toughness value, which was 26.171 KJ/m2.

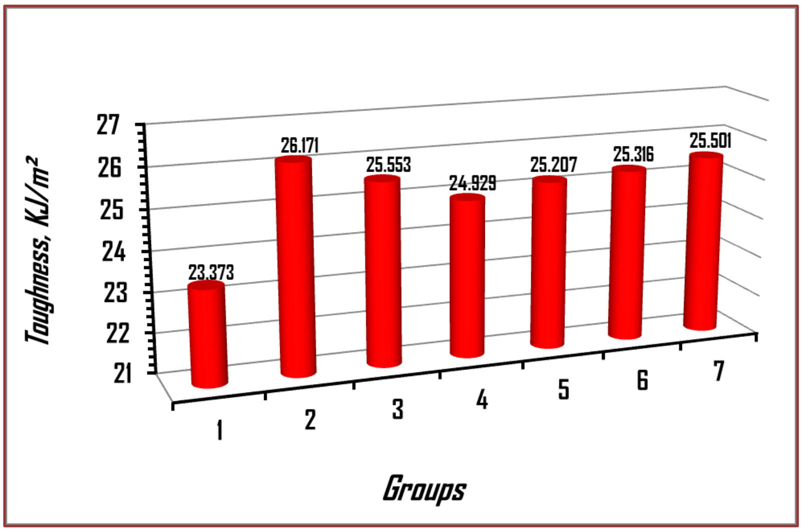

Figure 4: Result of the Toughness, KJ/m^2

V. CONCLUSIONS

The conclusions that follow can be formed from the samples heat treatment and cooling results in distilled water at various temperatures after these outcomes have been analyzed:

1. The heat-treated specimens' impact resistance value was higher than the untreated specimens'. The strong martensite lattice alloys created after heat treatment procedures are the primary cause of the enhanced resistance to impact load.
2. According to the results, the average values of the pendulum angles of the six heat-treated complexes have an angle of elevation that is higher than the average values of the original group. The corresponding decreases in these groups' values were 0.93, 0.75, 0.52, 0.60, 0.64, and 0.71%.
3. Results for the impact strength of the six heat-treated groups' average values in comparison to the first group's average values lead to a conclusion. These groups' respective values increased by 11.96, 9.33, 6.66, 7.85, 8.31, and 9.10 %.
4. The toughness of the six heat-treated groups' average values in comparison to the original group's average values is inferred from the results. These groups' respective values increased by 11.96, 9.33, 6.66, 7.85, 8.31, and 9.10 %.
5. The group that was cooled in distilled water at zero temperature had the best toughness value, according to the difference in coolant temperatures.

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