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STUDY OF THE THERMAL EFFECT OF HOT AND COLD WORKING ON THE MECHANICAL PROPERTIES OF MEDIUM CARBON STEEL

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ABSTRACT

Medium carbon steel is widely used in industries due to its favourable strength and flexibility. However, they are highly prone to deformation processes that affect their impact resistance and corrosion rate. This research examines the effects of hot and cold working on the mechanical properties of medium-carbon steel. Experimental tests were conducted on medium carbon steel samples subjected to hot and cold working treatment procedures via funnels for the hot working. Deformation techniques such as rolling and bending are employed by subjecting the materials to a high temperature of 900ºC. At the same time, in this study, cold working uses room temperature between 0oC to 22 ºC for both rolling and bending. The results show that hot bending improves the hardness property in the bending analysis, having 185.64, as opposed to cold bending, which is 174.33. It can be seen that the cold rolling treatment of medium carbon steel increases the hardness property by 179.84 compared with hot rolling techniques, which have a hardness of 161.63. The results from the rolling test show that the tensile stress at the yield point of the zero slopes is lower during the hot working process, having 598.05090 MPa, compared with the cold working results of 665.43718 MPa. However, the results of the elasticity modules show that hot working increases it with a value of 32885.24170 MPa compared with 28923.17810, respectively. It can be concluded that parameter optimization of the specification of medium carbon steel determined the specific treatment needed for the manufacturing industry to produce quality materials.

Keywords: medium carbon steel, grain refinement, hot and cold working, thermal effects, mechanical properties.

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1. INTRODUCTION

Medium carbon steels are a class of steels that contain a carbon content ranging from 0.25% to 0.60%. These steels are widely used in various industries due to their strength, toughness, and wear resistance [1]. Different manufacturing processes, such as hot working and cold working, can significantly influence the mechanical properties of medium carbon steel. Hot and cold working are two distinct metalworking processes that involve material deformation at elevated and room temperatures, respectively [2]. Each process uniquely affects the microstructure and mechanical properties of medium carbon steel. Hot working refers to the deformation of steel above its recrystallisation temperature, typically above 900°C for medium carbon steels [3]. During hot working, the steel undergoes significant plastic deformation, resulting in the refinement of the grain structure. This refinement occurs due to dynamic recrystallisation, where new, smaller grains nucleate and grow within the deforming material [4]. As a result, hot working can improve the mechanical properties of medium carbon steel, such as increasing its strength, ductility, and toughness. It also helps eliminate residual stresses and improve the steel's homogeneity [5]. Zhang *et al*. [6] investigated the behavior of low-carbon steel when exposed to thermal deformation. The researchers conducted a thermal compression test using the Gleeble-1500 thermal simulator. The steel samples were subjected to a single-pass compression during the trial at temperatures ranging from 900 to 1200 °C, with strain rates varying from 0.01 to 10 s−1. Two constitutive models were developed by analyzing the experimental data: a strain-compensated Arrhenius model and a physical model based on dynamic recrystallisation. The accuracy of these models was assessed using correlation coefficients and average absolute relative errors. Comparing the models, it was found that both can effectively predict the behavior of the steel during hot deformation. In addition, processing maps were generated at strain levels of 0.2, 0.4, 0.6, 0.8, and 1.0 to determine the optimal processing conditions for the tested steel. These maps revealed two regions of plastic instability: one at low temperatures with high strain rates and another at high temperatures with high strain rates. Consequently, it is recommended to avoid hot working processes within these areas. The optimal processing conditions for the tested steel were identified as temperatures ranging from 1100 to 1175 °C and strain rates between 1.35×10−1 and 6×10−1 s−1.

According to Tang *et al*. [7], the hardness of metallic materials plays a significant role in determining their resistance to wear. It has been noted that the wear resistance can be assessed by considering the hardness ratio to Young's modulus. A higher H/E ratio indicates more excellent wear resistance. However, this ratio does not hold for materials that have undergone strain hardening. The authors have observed that increasing the H/E ratio through cold-working does not improve wear resistance in such cases. This is because plastic deformation during cold-working introduces crystalline defects like dislocations, which compromise the integrity of the crystal structure. To verify these observations, we conducted molecular dynamics (MD) simulations to study the impact of cold-working on iron's mechanical properties and wear resistance, serving as a sample material. Additionally, we conducted relevant experimental investigations on medium carbon steel to gather more information. The MD simulations revealed how strain-induced defects affected the metal's mechanical properties and wear resistance. Experimentally, the study measured and analyzed changes in hardness, Young's modulus, wear loss, and electron work function of the steel resulting from cold-rolling. The modelling and experimental studies demonstrate that cold-working increases hardness but decreases Young's modulus due to damage to the overall atomic bond strength. Consequently, a more significant increase in the H/E ratio provides less benefit to wear resistance when cold-working is employed. However, the microstructural changes and resulting mechanical properties induced by hot-working and cold-working processes on medium carbon steel still need to be fully understood. Investigating and comprehending how hot working and cold working affect medium carbon steel's microstructure and mechanical properties is necessary. Understanding the specific changes in grain structure, dislocation density, and residual stresses caused by these processes is crucial for optimising manufacturing techniques and selecting appropriate forming methods to achieve desired material properties. Additionally, the impact of processing parameters, such as temperature, strain rate, and deformation conditions, on medium carbon steel's resulting microstructure and properties requires further examination. Determining the optimal ranges of these parameters will help control and manipulate the material's properties to meet specific application requirements [8].

Furthermore, the study should address the differences and trade-offs between hot-working and cold-working processes regarding the resulting microstructure, mechanical properties, dimensional stability, and residual stresses. This will assist in determining the most suitable manufacturing approach for medium carbon steel in various industrial applications. By addressing these research gaps and providing comprehensive insights into the effect of hot working and cold working on medium carbon steel, the study aims to advance materials science and metallurgy, enabling improved manufacturing processes and developing high-performance materials for diverse engineering applications. The aim of the study on the effect of hot working and cold working on medium carbon steel is to investigate and understand how these manufacturing processes impact the material's mechanical properties. The study aims to provide insights into the relationship between processing conditions, deformation mechanisms, and resulting material properties.

2. METHODOLOGY

2.1 Materials Used

Medium carbon steel of A830-1045 contains 0.43-0.50% carbon and other alloying elements such as manganese, silicon, and sometimes small amounts of elements like chromium or nickel. The Equipment and Tools:

Heating equipment: Depending on the chosen hot working process, you may need a furnace, an induction heater, or other heating equipment capable of reaching and maintaining the desired temperatures for hot working.

Hot Working Equipment: Various equipment may be required for specific hot working processes, such as hot rolling mills, forging presses or hammers, or extrusion machines.

Cold working equipment: Cold working processes typically involve rolling mills, drawing machines, or forging presses suitable for cold deformation.

Annealing Furnace: If intermediate annealing steps are included in the study, an annealing furnace capable of controlled heating and cooling is necessary.

Mechanical testing machines: Tensile testing machines, hardness testers, impact testing machines, and other relevant mechanical testing equipment are needed to evaluate the mechanical properties of the samples.

2.2 Sample Preparation and Procedure of the Bending, Squeezing and Rolling Process

The hot bending process heats the medium carbon steel to about 960oC and gradually applies bending force via bending machining to produce the desired shape. For the binding Process, the sample length of the medium carbon steel is 30 mm, the diameter is 4 mm, and the maximum tensile stress applied is 686.88 MPa, and 534 MPa for the hot and cold bending process was employed as shown in Figure-1.

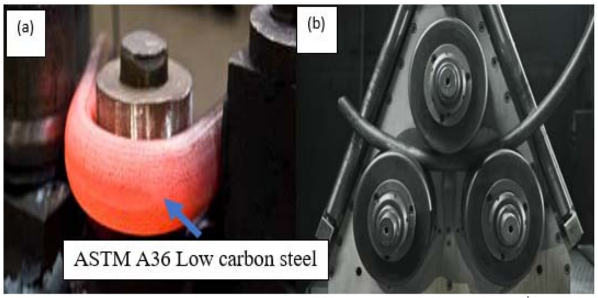

Figure-1. (a) Hot bending and (b) Cold bending process of steel.

Squeezing is a procedure that employs a compressive force via squeezing medium carbon steel into a cylinder to reduce the thickness of a sheet of metal. Squeezing sheet metal using cylinders is a process similar to traditional sheet metal squeezing, but it utilises cylinders instead of a punch and a die to apply the compressive force. For the squeezing process, the sample length of the medium carbon steel is 28 mm, the diameter is 4 mm, and the maximum tensile stress applied is 644.81 MPa and 731.41 MPa for the hot and cold squeezing process.

The steel is heated to a temperature above its recrystallisation temperature in hot rolling, typically 9600C for most steels. The heated steel is then passed through a series of rollers, which apply pressure to shape and form the material. For the Rolling Process, the length of the medium carbon steel is 28 mm, the diameter is 4 mm, and the maximum tensile stress applied is 598.05 MPa and 665.44 MPa for the hot and cold rolling process. After achieving the desired shape, the steel may be cooled and controlled to improve its mechanical properties. The steel is processed at room temperature or slightly below in cold rolling, typically between 20-22 °C (68-72 °F). The cold rolling process normally involves passing the steel through a series of rollers several times, with each pass reducing the thickness of the steel both setup illustrations of the cold and hot rolling are shown in Figure 2.

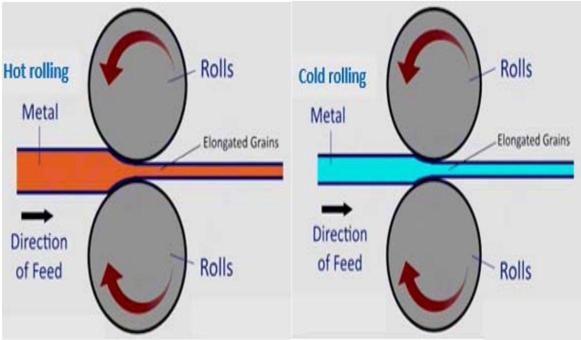

Figure-2. The hot and cold rolling process of metals.

2.3 Procedure for the Mechanical Properties

The mechanical properties analysed after the experiment are hardness, impact, tensile stress, and strain analysis.

The hardness and impact tests assess a material's toughness and resistance to deformation, such as low-carbon steel, under impact loading conditions [9]. This test provides valuable information about the material's ability to absorb energy and resist fracture. The Brinell Hardness Test Machine was employed for the hardness text during an indentation angle of 150.

For the tensile test, the sample is placed on the tensile machining, which is held at both ends and slowly, the tensile force is applied to pull the materials until they reach a fracture point. It has a maximum load of 8631.49613 for bending, 7515.32912 for rolling, and 7515.32912 for squeezing. The load applied during the experiment is converted to stress values for the tensile test, and the displacement is analysed as strain value. Tensile specimens with a gauge length of 25 mm and a circular cross-section diameter of 12.5 mm are machined by ASTM E-8M, as shown in Figure-3.

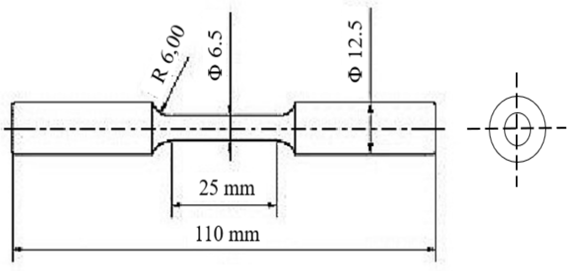

Figure-3. Shows the tensile test specimen.

3. RESULTS AND DISCUSSIONS

The results analysis of the experiment is depicted in this section. This section explains the thermal effects of hot and cold working on the mechanical properties, such as the hardness of the materials, the impact of the bending and rolling process on the A830-1045, and the tensile stress and strain properties of A830-1045 medium-carbon steel.

3.1 Effects of the Hot and Cold Process on Hardness

The hardness results after the hot and cold bending and the rolling rotation are shown in Figure-4. It can be seen that the cold rolling treatment of medium carbon steel increases the hardness property by 179.84 compared with hot rolling techniques, which have a hardness of 161.63. Furthermore, the resultant effects are different when applying the hot and cold bending techniques. In the bending analysis, hot bending improves the hardness property, having 185.64, as opposed to cold bending, which has 174.33. These results have proven that the mechanical treatment of medium carbon steel is essential because hot rolling or bending significantly affects the plastic deformation of the materials, which results in refining the structural grain sizes. The grain size refinement takes place due to the dynamic recrystallisation. The process reduces the grains of the microstructure of the medium carbon steel, which results in improved homogeneity [10-11]. This homogeneity helps to enhance the balancing structure and increases the hardness and ductility properties.

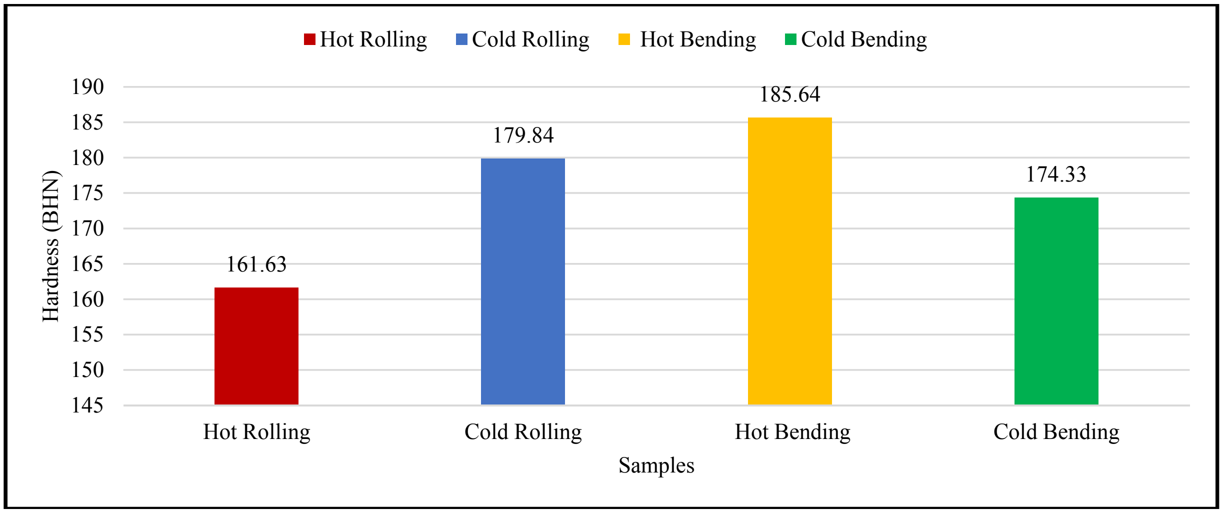

Figure-4. Effects of hot and cold treatment on the medium carbon steel hardness.

3.2 Effects of the Hot and Cold process on impact

The 4-piece specimen, which has undergone heat treatment and temperature 900°C, was employed to experience the charpy impact test. From the results shown in Figure-5, the hot bending treatment has the highest value at 65.74 J/mm^{2,} compared with the cold bending treatment at 61.7 J/mm^2. The trend of the result was observed for the hot rolling treatment, which increases the impact resistance compared with the cold rolling, with 58.37 J/mm^2 and 57.01 J/mm^{2,} respectively. The study of Ismail *et al.* [12] was conducted on the influence of heat treatment on the mechanical properties of medium carbon steel by studying the hardness and impact text. The study supports the findings of this research.

3.3 Effects of the Hot and Cold Treatment on Tensile Stress and Strain Properties of the Medium Carbon Steel

Figure-6 and Figure-7 show the tensile stress and strain analysis of the hot-treated and cold-treated medium carbon steel. Also, Tables 1 and 2 depict the specimen parameters for the tensile strength analysis. The results show that hot working (heat treatment) increases mechanical qualities like tensile strength, yield strength, ductility, corrosion resistance, and creep rupture, in addition to developing hardness and softness [13-14].

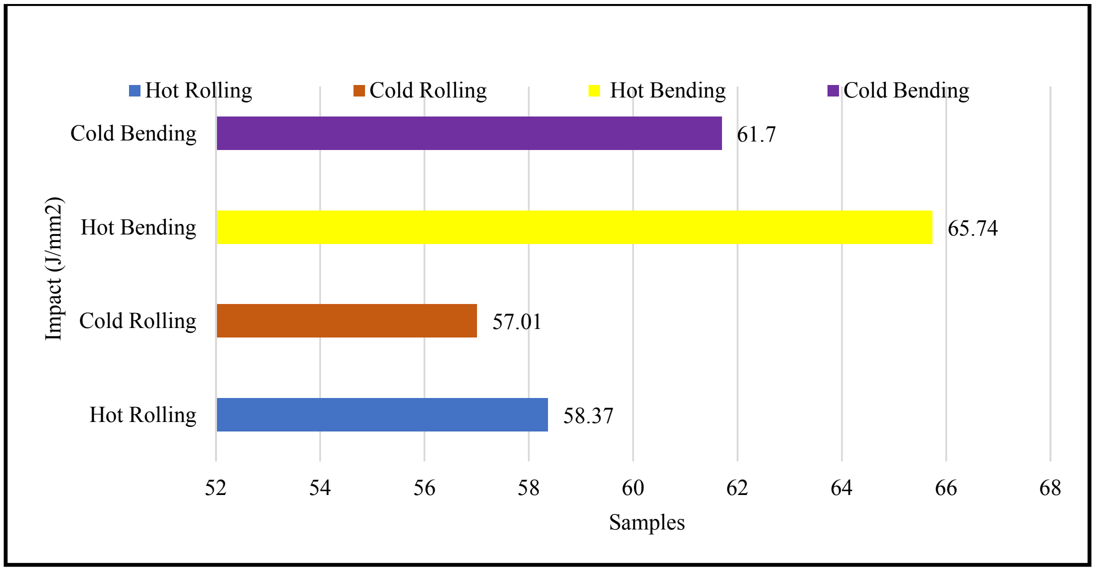

Figure-5. Hot and cold process effect of the impact results for medium carbon steel.

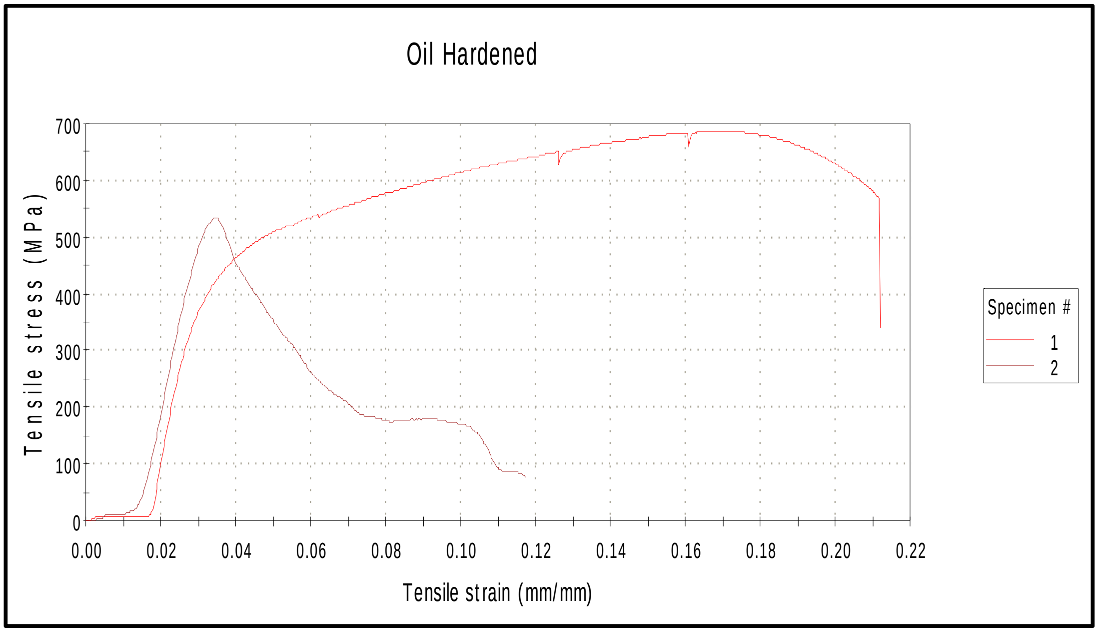

Figure-6. Hot bending and cold bending analysis on the tensile stress and strain of medium carbon steel.

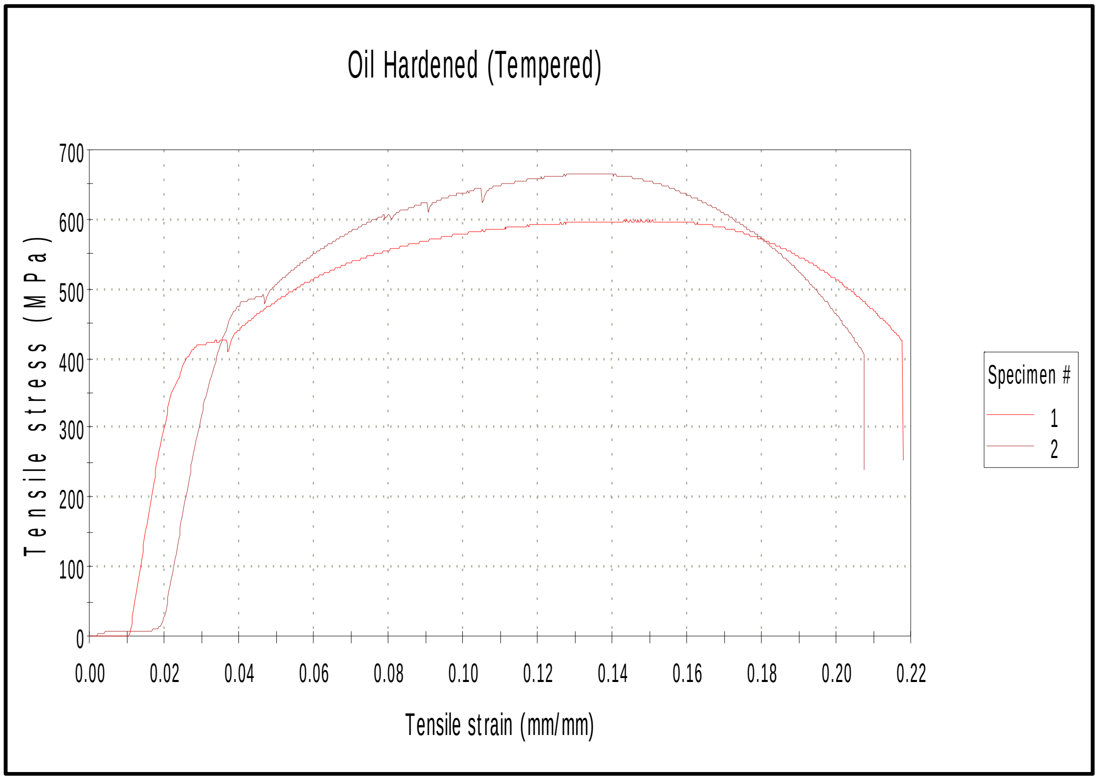

Figure-7. Hot rolling and cold rolling analysis on the tensile stress and strain of medium carbon steel.

These procedures also increase the effectiveness of the machining and increase their adaptability. The results from the bending test show that the tensile stress at the yield point of the zero slope is high at the hot working process, having 686.87265 MPa as compared with the cold working results of 534.02078 MPa, with modules of elasticity 32724.06 MPa as compared with 32547.01, respectively as shown in Table-3.

The results from the rolling test show that the tensile stress at the yield point of the zero slope is lower at the hot working process, having 598.05090 MPa as compared with the cold working results of 665.43718 MPa. This study aligns with the results of [15-18]. However, the results of the modules of elasticity show that the hot working increases it with a value of 32885.24170MPa compared with 28923.17810, respectively, as shown in Table-4.

Table-1. Parameters analysis of the hot and cold bending.

	Length (mm)	Diameter (mm)	Maximum Tensile stress (MPa)
1	30.00000	4.00000	686.87265
2	30.00000	4.00000	534.02078
Mean	30.00000	4.00000	610.44671
Standard Deviation	0.00000	0.00000	108.08259

Table-2. Parameters analysis of the hot and cold rolling.

	Length (mm)	Diameter (mm)	Maximum Tensile stress (MPa)
1	28.00000	4.00000	598.05090
2	28.00000	4.00000	665.43718
Mean	28.00000	4.00000	631.74404
Standard Deviation	0.00000	0.00000	47.64930

Table-3. Results of the yield value for medium carbon steel after hot and cold bending.

	Load at Break (Standard) (N)	Tensile strain at Break (Standard) (mm/mm)	Tensile extension at Break (Standard) (mm)	Energy at Break (Standard) (J)	Tensile stress at Yield (Zero Slope) (MPa)	Modulus E-modulus (MPa)
1	6884.42066	0.21196	6.35881	42.73047	686.87265	32724.06311
2	970.31193	0.11722	3.51656	9.83669	534.02078	32547.01538
Mean	3927.36630	0.16459	4.93769	26.28358	610.44671	32635.53925
Standard Deviation	4181.90639	0.06699	2.00977	23.25941	108.08259	125.19165

Table-4. Results of the yield value for medium carbon steel after hot and cold rolling.

	Load at Break (Standard) (N)	Tensile strain at Break (Standard) (mm/mm)	Tensile extension at Break (Standard) (mm)	Energy at Break (Standard) (J)	Tensile stress at Yield (Zero Slope) (MPa)	Modulus (E-modulus) (MPa)
1	5306.95394	0.21785	6.09981	37.94438	598.05090	32885.24170
2	5099.80731	0.20744	5.80844	37.05836	665.43718	28923.17810
Mean	5203.38062	0.21265	5.95412	37.50137	631.74404	30904.20990
Standard Deviation	146.47479	0.00736	0.20603	0.62651	47.64930	2801.60204

The results in this study are in line with the work of Zou *et al*. [19] having investigated that the ultimate tensile strength higher than 1110 MPa and an overall elongation of 34.4% was achieved in the annealing cold rolling process of a medium steel, the resultant sample displays remarkable mechanical properties. These properties surpass those of the sample generated by traditional cold rolling. The work of Yuzbekova et al. [20] was conducted to determine how thermoforming affected the strength and fracture toughness of 0.4%C-2%Si-1%Cr-1%Mo-VNb steel. Plate rolling and tempering at the same 600 °C result in a 25% increase in yield stress and a factor of about 10 in Charpy V-notch energy of impact. As rolling reduction increases, the grains reposition and elongate in the direction of the rolling direction (RD) and a strong {001} <110> (rotated cube) texture element develops, which significantly increases fracture toughness. After temperature-forming at 600 °C with a total strain of

1.4, a lamellar framework with a lattice dislocation percentage of approximately 1015 m−2 and boundary spacing of 72 nm emerges. The final grain size is tailored by the abrupt phase disintegration, which also affects the evolution of precipitates and recrystallized kinetics. In addition, the appearance of α and γ fiber in the BCC phase is used to study the formation of textures following cold rolling and annealing. Lastly, a thorough microscopic method has been used to establish a correlation between the associated microstructures of the studied samples and their overall tensile response [21].

4. CONCLUSIONS

The effect of hot and cold working on medium carbon steel has been extensively studied and analysed in this project. Hot working involves the deformation of steel at elevated temperatures, while cold working refers to the deformation at room temperature. Both processes have significant implications for the microstructure, mechanical properties, and overall performance of medium carbon steel. Hot working promotes recrystallisation, improving grain refinement, ductility, and enhanced formability. It also eliminates residual stresses and improves the homogeneity of the material. However, excessive hot working may cause grain growth and reduce the strength and hardness of the steel. Therefore, careful control of processing parameters is essential to achieve the desired balance of properties. On the other hand, cold working induces strain hardening and increases the strength and hardness of medium carbon steel. It introduces dislocations and results in a refined grain structure. However, cold working can also lead to reduced ductility and increased susceptibility to cracking. Annealing processes, such as recrystallisation or stress-relief annealing, can restore ductility and relieve residual stresses after cold working. The choice between hot and cold working depends on the specific application and desired properties. Hot working is typically employed for shaping processes like forging, extrusion, and rolling, where plastic deformation is required at elevated temperatures. Cold working is more suitable for applications prioritising strength, hardness, and dimensional accuracy, such as cold-formed components, fasteners, and springs.

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