“Effect of Heat Treatment Variables on Microstructure and Mechanical Properties of Aisi 4130 Low Alloy Steel”

Jignasha Parmar[1]*, Dr. Vandana J Rao[2]

[1]Assistant Professor, Department of Metallurgical and materials Engineering, [The maharaja Sayajirao university], Baroda, India

[2]Associate Professor, Department of Metallurgical and materials Engineering, [The maharaja Sayajirao university], Baroda, India

DOI: https://doi.org/10.51583/IJLTEMAS.2026.150300102

Received: 31 March 2026; March: 06 April 2026; Published: 21 April 2026

ABSTRACT

The present study investigates the effect of heat treatment on the microstructure and mechanical properties of AISI 4130 steel. The material was subjected to a sequence of normalizing, hardening, and tempering treatments to evaluate the influence of tempering temperature on performance characteristics. Normalizing was carried out at 890°C followed by air cooling, resulting in a refined ferrite–pearlite microstructure. Subsequently, hardening was performed at 860°C and followed by quenching to obtain a martensitic structure.

Tempering was conducted at two different temperatures, 472°C (Sample A) and 518°C (Sample B), to study the variation in mechanical behavior.

The results highlight that tempering temperature plays a critical role in tailoring the balance between strength and toughness in AISI 4130 steel. This study provides useful insights for optimizing heat treatment parameters for engineering applications requiring a combination of mechanical performance and structural reliability.

Keywords: Heat treatment, Normalizing, Hardening, Tempering

INTRODUCTION

In this modern world we come across various engineering materials, but when these materials are scrutinized, we find that steel remains predominant. Steel has provided modern engineer the leverage to tailor engineering components ranging from a small nut to huge skyscrapers.

Amongst various classes of steel, medium carbon steels stand apart and are considered to be the backbone of modern industry. Steel can briefly be divided into three types; one of them is medium carbon steel. A medium carbon steel having 0.80-1.10% Cr, 1% Ni and 0.28-0.33 C with Tempered Martensite structure can be considered as a medium carbon steel. Medium carbon steels occupy a unique status as engineering materials by virtue of their excellent combination of properties such as high strength, adequate ductility, toughness and good corrosion resistance. These steels find extensive application in chemical plants, power generation equipment’s, in gas turbines as turbine and compressor blades and discs, aircraft engine components and fittings and in marine components.

These steels can be heat treated to obtain a wide range of mechanical properties to meet the requirements of specific application AISI 4130 is one of the most potentially attractive steels in this medium carbon steel class used extensively for parts requiring a combination of high tensile strength, good toughness and corrosion resistance. 4130 is a high chromium-low nickel low hardenability Medium carbon steel and generally used as hardened and tempered in the tensile range 655 min MPa, Brinell range 204-244 BHN. Characterised by very good corrosion resistance in general atmospheric corrosive environments, good resistance to mild marine and industrial atmospheres, resistant to many organic materials, nitric acid and petroleum products coupled with high tensile and high yield strength plus excellent toughness in the hardened and tempered condition. So AISI 4130 is used in highly-stressed aircraft components, pump shafts and valve stems etc.

Generally heavy components of AISI 4130 steel like shaft, axle etc can be manufactured by open die hot forging (heavy forging). The forging of type AISI 4130 steel is carried out between the ranges of 900 to 1200 °C followed by slow cooling up to room temperature. The slow cooling of materials shall be done by either furnace or insulating materials. Normalizing process (after cooling of heavy forged part) immediately required for forged products to make them machinable after normalizing followed hardening and tempering.

Experimental Work

Five specimens were prepared for microstructural characterization and mechanical testing, including hardness, tensile, and impact tests. Metallographic preparation was carried out in accordance with ASTM E3, followed by etching as per ASTM E407 to reveal the microstructure. Brinell hardness measurements were performed according to ASTM E10 using a standard ball indenter, and the reported values represent the average of three readings. Tensile testing was conducted in accordance with ASTM E8/E8M using a universal testing machine to determine strength and ductility parameters. Impact toughness was evaluated using the Charpy impact test as per ASTM E23.

Figure 1: Microstructure of normalized Steel Specimen (Ferrite-pearlite),2% Nital

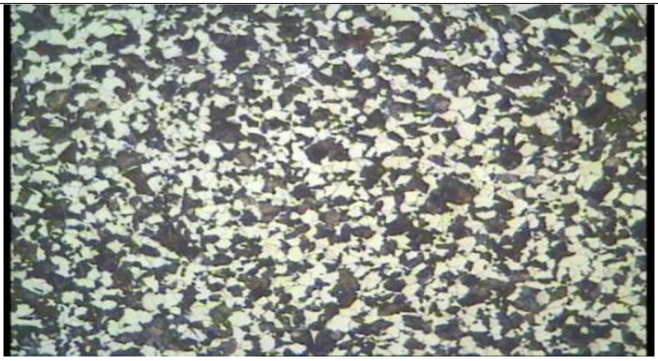
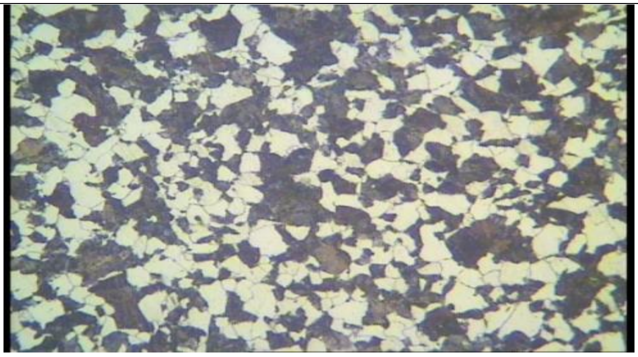
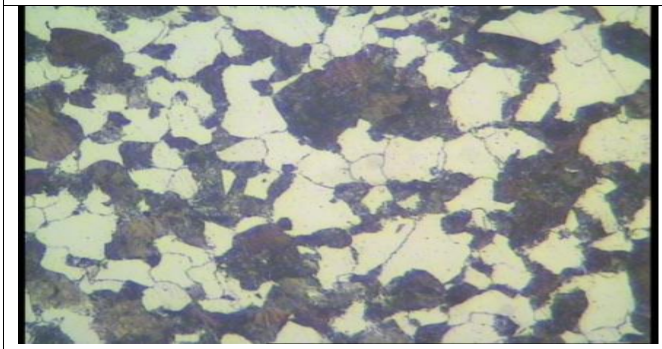
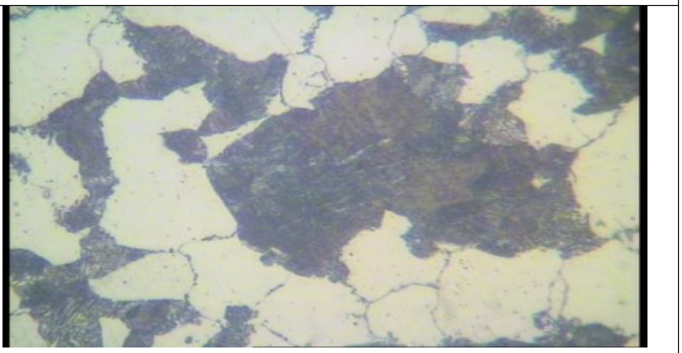
	
100 X	200 X
	
400 X	1000 X

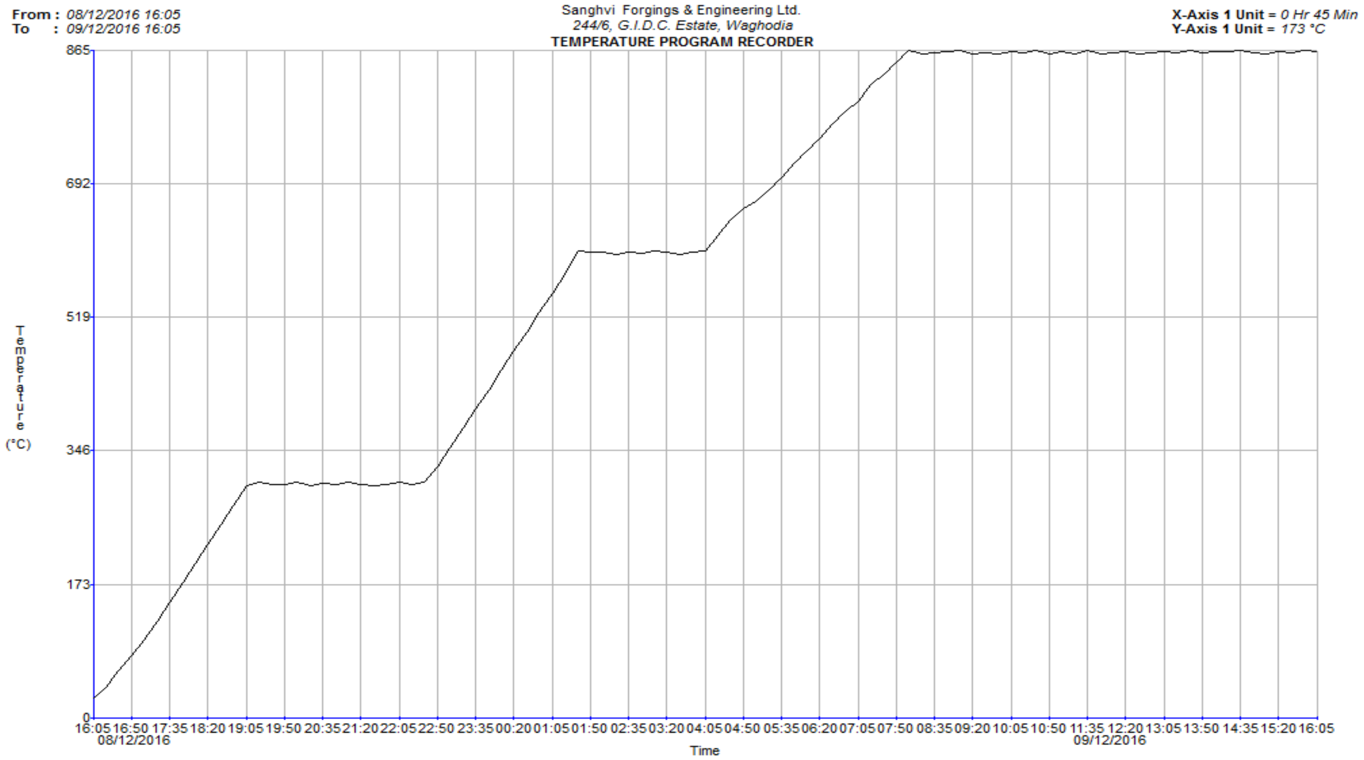
Table 1: Parameter variables

Object dimension (mm)	**Normalizing Temp (^oC)**	**Tempering Temp (^oC)**
Sample A (390 Ø x 265) L	860^{o}C	450 + 22 = 472
Sample B (390 Ø x 265) L	860^{o}C	472 + 46 =518

Experiment for Sample A

Hardening

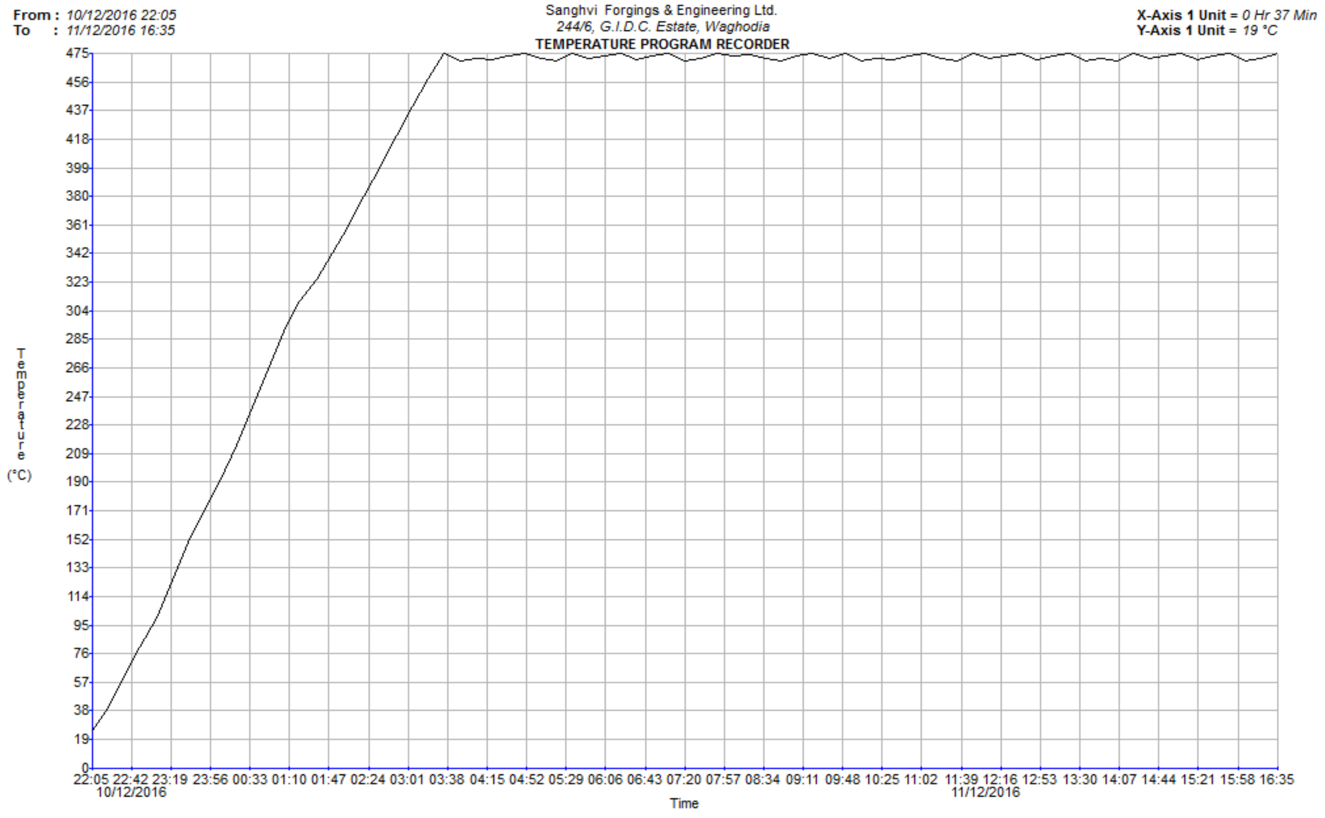
Figure 2: Heat Treatment Cycle showing hardened Sample A at 860 ^{o}C(Holding time 8Hrs) and water Quenched, Resulting in Approximately cooling rate (0.64 °C/s).



This graph also refer for date 19/12/2016, 22/12/2016, 26/12/2016.

Tempering

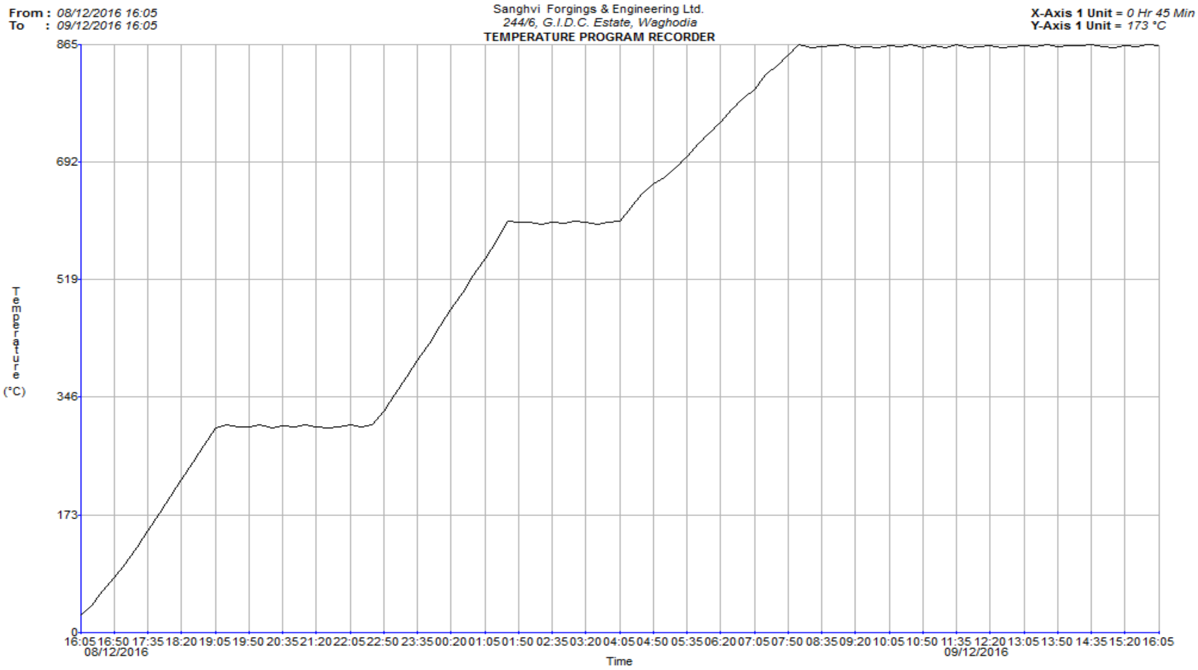
Figure 3: The hardened sample A Was Tempered at 472 ^{o}C, for 13 hr and air cooled.



Experiment for Sample B

Hardening

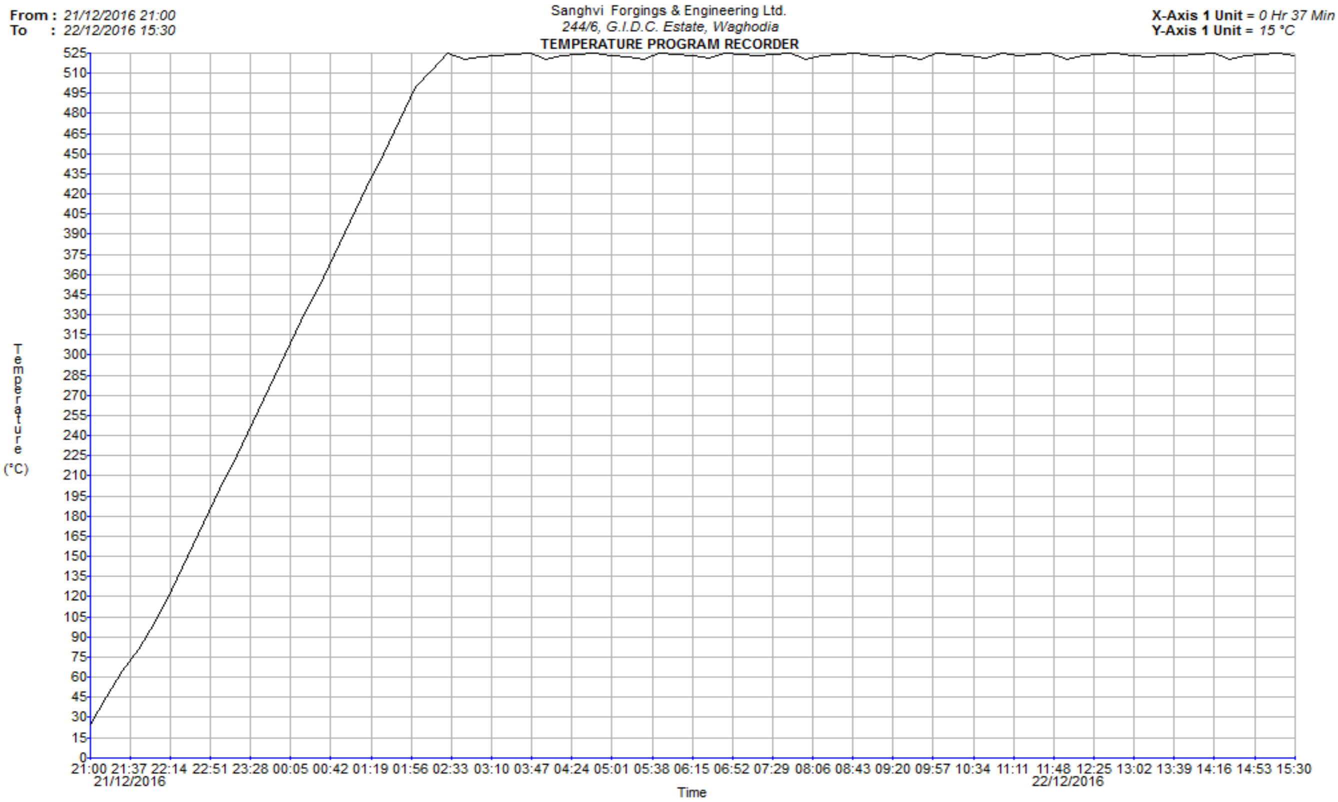
Figure 4: Heat Treatment Cycle showing hardened Sample B at 860 ºC (Holding time 8 Hrs) and water Quenched, Resulting in Approximately cooling rate (0.11 °C/s)



This graph also refer for date 19/12/2016, 22/12/2016, 26/12/2016.

Tempering

Figure 5: Tempering cycle Shows The hardened sample B Was Tempered at 518ºC, for 13 hr and air cooled.



RESULTS

Table 2: Result for Sample A (Tensile, Micro and Impact Testing)

Sample (Ø390 X 265 mm L)	Hardness after hardening at 860 °C (BHN)	Hardness after tempering at 472 °C (BHN)	Hardness after tempering at30 mm depth
A	382,382,364	312,297,312	262,252,262

Yield strength (MPa)	Tensile Strength (MPa)	Elongation (%)	Reduction Area (%)	Impact (Charpy V notch) Temp – 45 °C (J)	Avg.
L = 687	903	25	58.946	26,23,7	18.66
T = 816	908	25.30	55.198	12,19,10	13.6
R= 663	869	14.680	51.045	19,16,25	20

Where L = Longitudinal Direction, T = Transverse Direction, R=Radial Direction

Table 3: Result of Tensile Testing, Impact & Hardness to Experiment

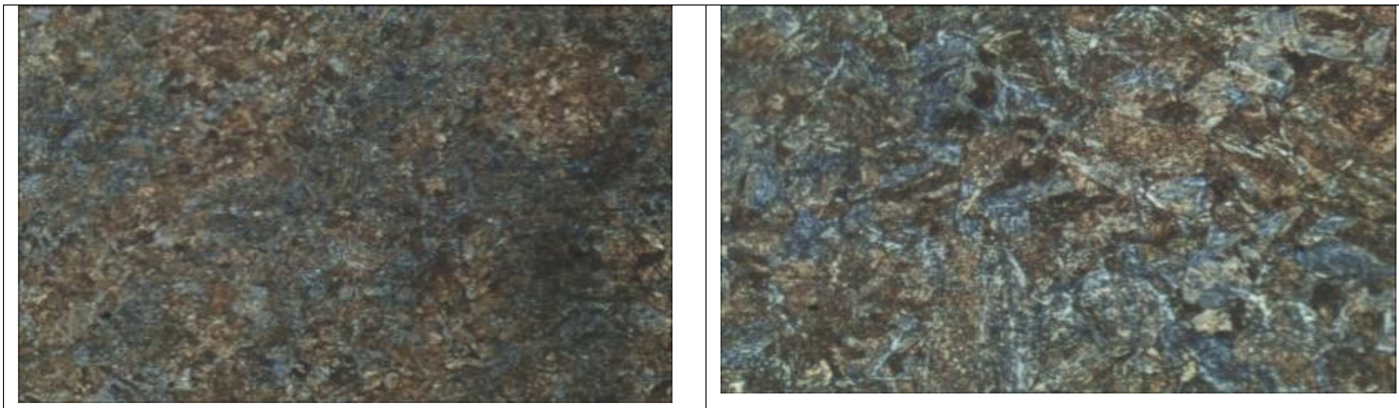
Sample (Ø390 X 265 mm L)	Hardness after hardening at 860 °C (BHN)	Hardness after tempering at 518 °C (BHN)	Hardness after tempering at 30 mm depth
B	382, 400, 419	382, 364, 400	242, 232, 242

Yield strength (MPa)	Tensile Strength (MPa)	Elongation (%)	Reduction Area (%)	Impact (Charpy V notch) Temp – 45 °C (J)	Avg.
L = 731	879	24.16	58.593	28,12,32	24
T = 730	887	22.02	50.709	30,20,13	21
R= 667	861	19.28	53.651	28,40,30	32.66

Where L = Longitudinal Direction, T = Transverse Direction, R=Radial Direction

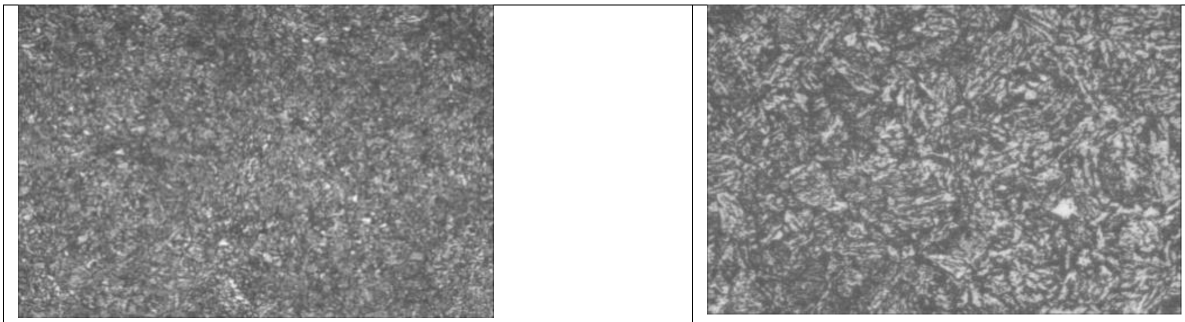
Microstructure Analysis after tempering

Figure 6: Microstructure of Tempered Sample A (tempered martensite & upper bainite, blue colour shows tempered martensite), Etchant Berasas.



100X	**400X**

Figure 7: Microstructure of Tempered Sample B (tempered martensite), Etchant 2% Nital



100X	**400X**

DISCUSSIONS

Normalizing at 890°C followed by air cooling resulted in a ferrite–pearlite microstructure due to the transformation of austenite under relatively slow cooling conditions. This microstructure provides a uniform and balanced combination of strength and ductility, serving as a suitable base for subsequent heat treatment. After quenching and tempering, the microstructure revealed the presence of tempered martensite and upper bainite. The blue-colored regions observed in the microstructure correspond to tempered martensite when etched with Berasa reagent, while 2% Nital etching confirmed the presence of tempered martensite. The formation of these phases indicates partial decomposition of martensite during tempering, contributing to improved toughness and reduced brittleness.

The cooling behavior significantly influenced phase transformation and mechanical properties. Experiment 1 exhibited a higher cooling rate (0.64 °C/s), whereas Experiment 2 showed a lower cooling rate (0.11 °C/s). Tempering at 472°C and 518°C reduced hardness and enhanced toughness, with higher tempering temperature promoting carbide coarsening and improved impact strength. A hardness gradient across the section was observed due to non-uniform cooling in the large specimen**.**

CONCLUSIONS

Hardening at 860°C followed by tempering significantly influences the balance between strength and toughness of the material.

Tempering at 472°C (Experiment 1) resulted in higher ultimate tensile strength but comparatively lower impact toughness due to the presence of tempered martensite along with upper bainite.

Tempering at 518°C (Experiment 2) led to improved impact energy and better toughness, attributed to the formation of a more uniform tempered martensitic structure.

REFRENCES

1. Poloprudský, J., Chlupová, A., Šulák, I., & Obrtlík, K. (2023). Effect of heat treatment on the microstructure and fatigue behaviour of AISI 4130 steel. *Metallic Materials/Kovove Materialy*, *61*(6).
2. Heidary, O., Mirzaee, O., Raouf, A. H., & Borhani, E. (2020). UP-quenched SAE 4130 steel: Mechanical properties assessment and bainite formation. *Materials Science and Engineering: A*, *787*, 139479.
3. Kachomba, T., Mutua, J., & Ngoret, J. (2024). The Effects of Heat Treatment on Mechanical Properties and Microstructure of Wire-arc Additive Remanufacturing of AISI 4130 Steel Components. *SSRG Int. J. Mech. Eng.*, *11*(4), 40-55.
4. ASM Handbook volume 1 Properties & selection Irons steels & High performance alloys
5. ASM Handbook Volume 14 – Forming & Forging..
6. Heat treatment - Principles & Techniques by T.V. Rajan
7. Metallographic Handbook by George F. Vander Voort.
8. Microscale & Macroscale Techniques in the Organic Laboratory by Mayo et al.
9. Physical metallurgy by Vijendra Singh.
10. Steels: Heat Treatment & Processing Principles by George Krauss