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"Study of Heat Treatment Variables on Microstructure and Mechanical Properties of Aisi 4130 Low Alloy Steel"

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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, 565°C (Sample A) and 655°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 stands 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.

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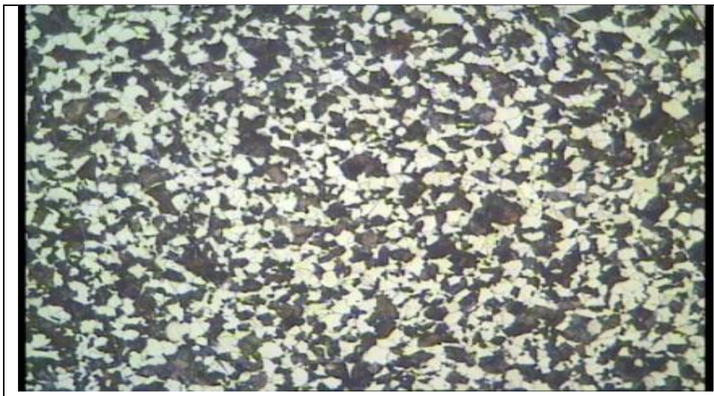
Generally heavy components of AISI 4130 steel like shaft, axle etc can be manufactured by open die hot forging (heavy forging). The forging of type AISI 4130 steel is carried out between the ranges of 900 to 1200 °C followed by slow cooling up to room temperature. The slow cooling of materials shall 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 METHODOLOGY

26 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. The Specimens (Sample A and Sample B) were normalized at 890°C with a holding time of 10hr, followed by air cooling

After normalizing, hardness is 184-191 BHN,

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



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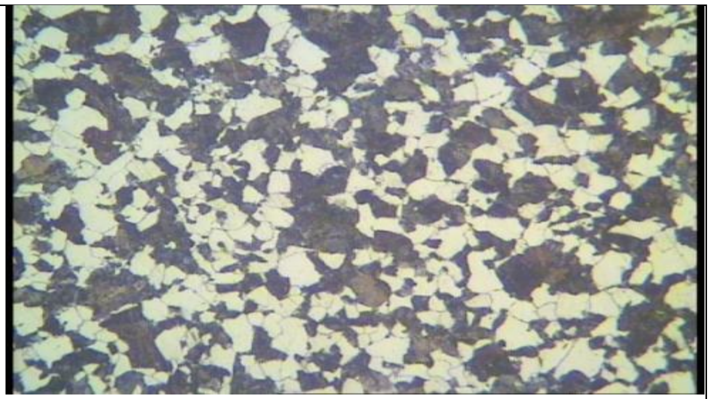

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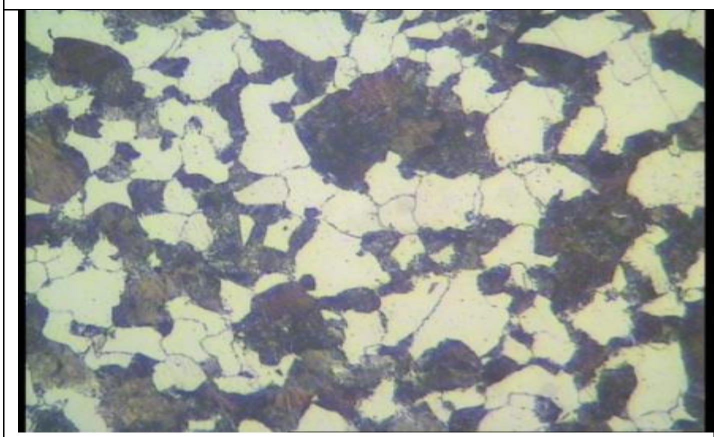

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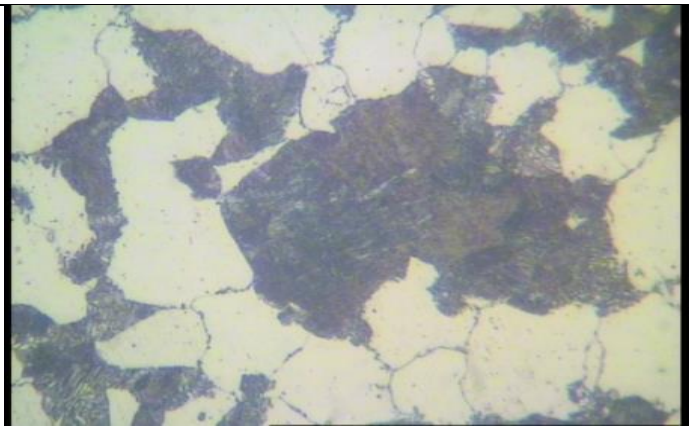

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Table 1: Parametric- variables

Object dimension (mm)	Normalizing Temp	Tempering Temp (^{0} C)
Sample A (390 Ø x 210 L)	860^o C	518+ 47 =565
Sample B (390 Ø x 265 L)	860^o C	565 + 90 = 655

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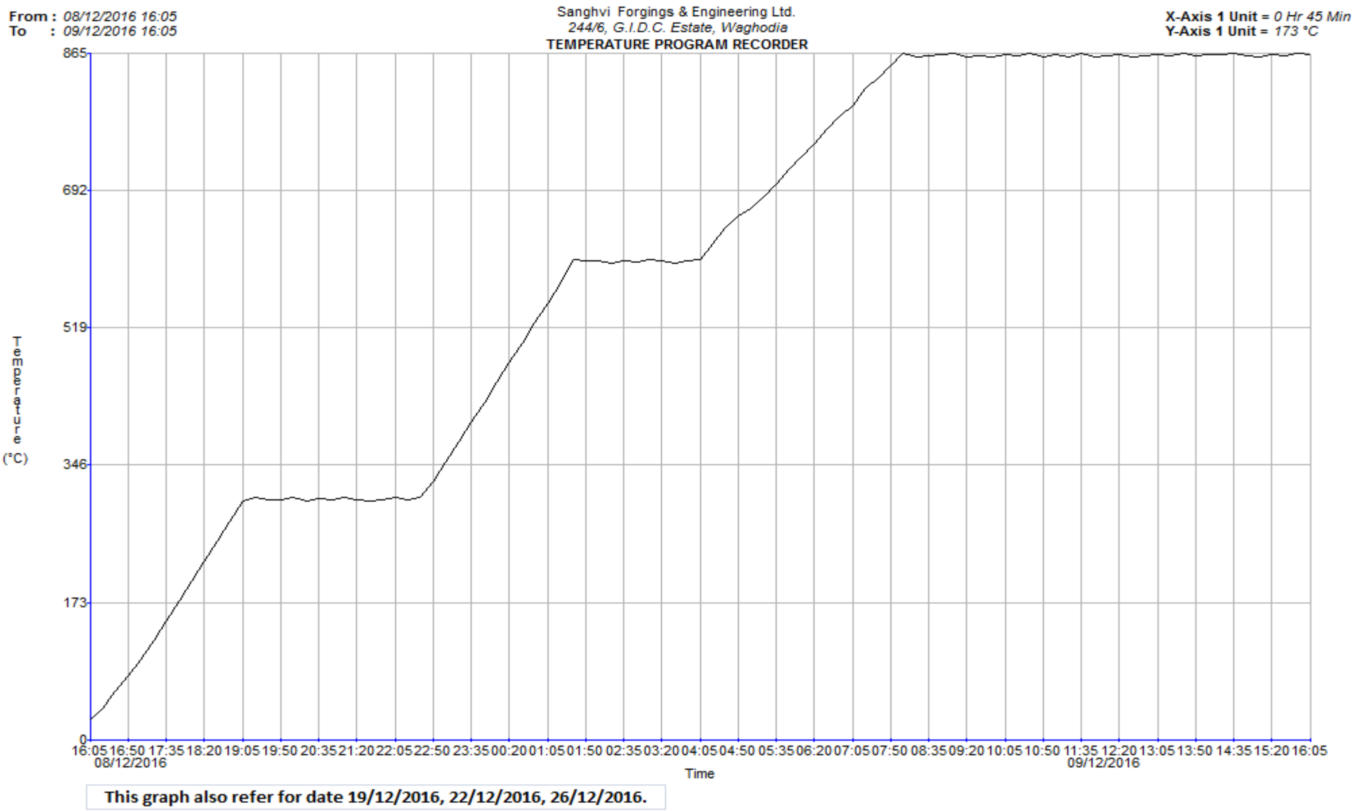
Experiment 1 For Sample A

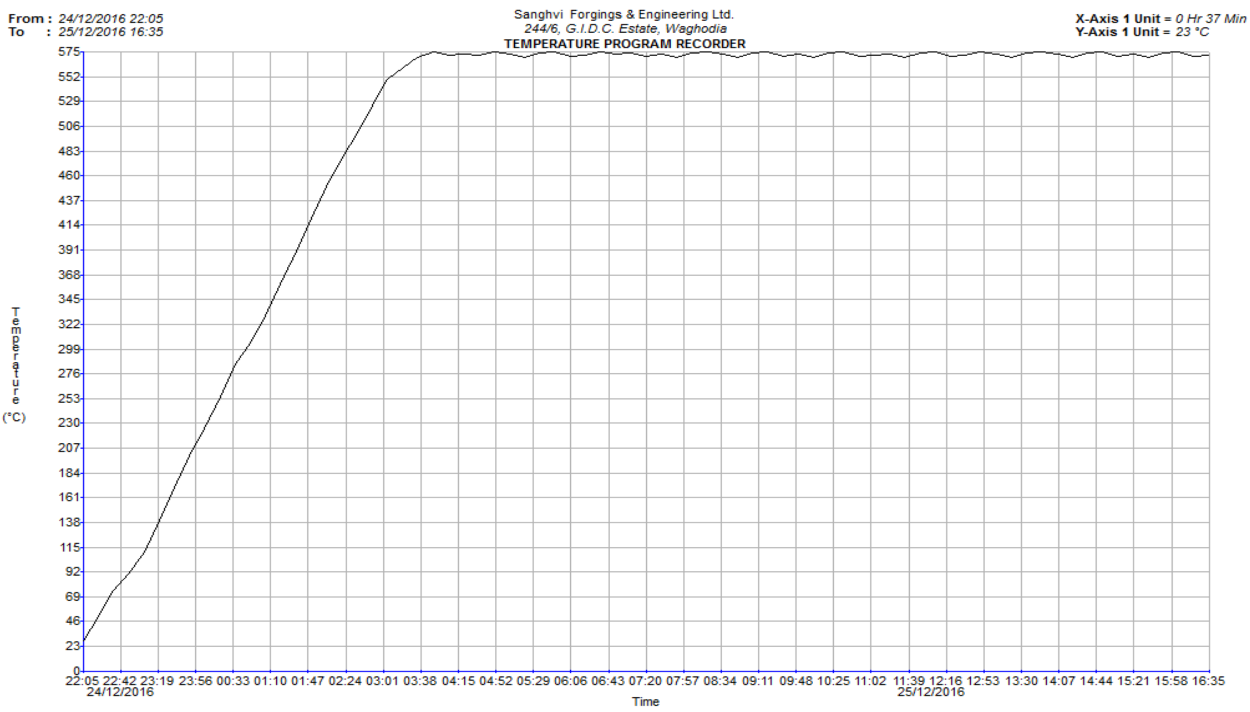
Hardening.

Figure 2: Heat Treatment Cycle showing hardened Sample A at 860 ^{o}C(Holding time 8Hrs) and water Quenched, Resulting in Approximately cooling rate (1.18 °C/s,).



Tempering

Figure 3: The hardened sample A Was Tempered at 565 ^{o}C, for 13 hr and air cooled.



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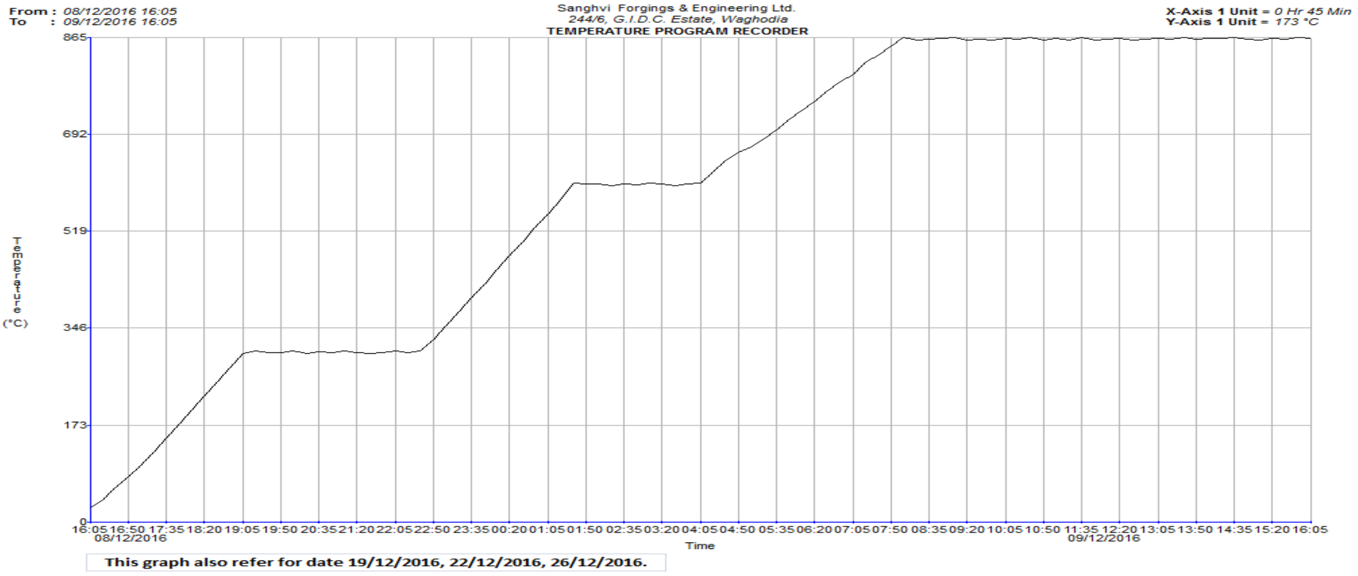
Experiment 2 for Sample B

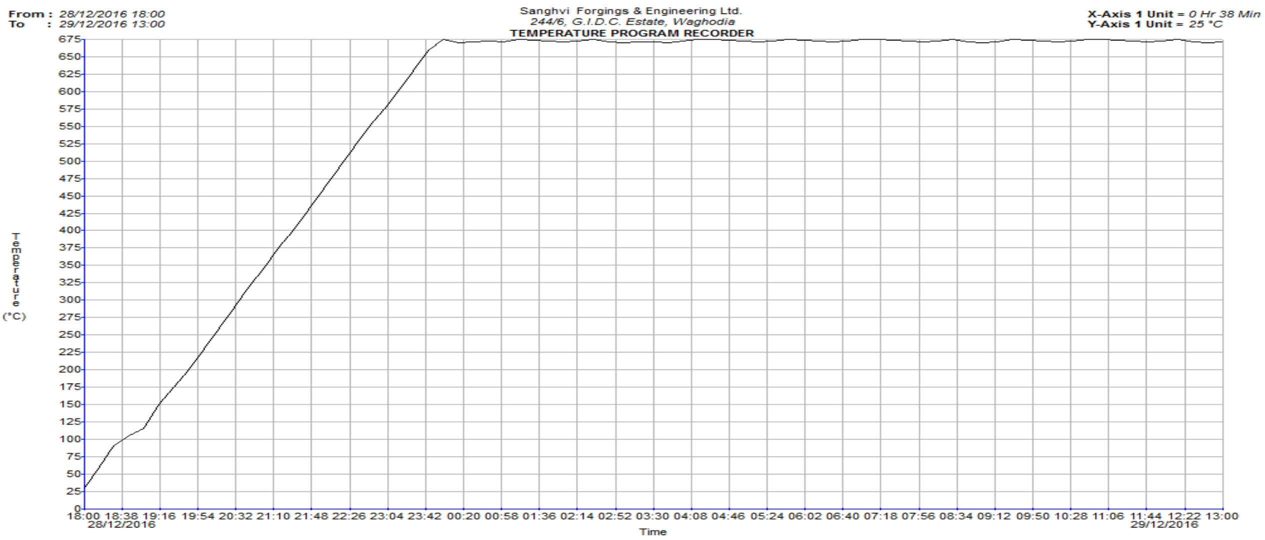
Hardening

Figure 4: Heat Treatment Cycle showing hardened Sample B at 860 °C (Holding time 8Hrs) and water Quenched, Resulting in Approximately cooling rate (0.64 °C/s).



Tempering

Figure5: The hardened sample B Was Tempered at 655 °C, for 13 hr and air cooled.



RESULTS AND DISCUSSION

Table 2: Result of Tensile Testing, Impact & Hardness for Sample A

Sample (Ø390 X 210 mm L)	Hardness after hardening at 860 ̊C (BHN)	Hardness after tempering at 565 ̊C (BHN)	Yield strength (MPa)
A	312,312,312	232,223,232	L = 627
			T = 597
			R= 621

Tensile Strength (MPa)	Elongation (%)	Reduction Area (%)	Impact (Charpy V notch) Temp – 45°C (J)	Avg
788	24.50	63.148	84,55,54	64.33
776	25.14	59.290	50,48,34	44
757	24.94	53.912	52,39,58	49.67

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

Table 3: Result of Tensile Testing, Impact & Hardness for Sample B

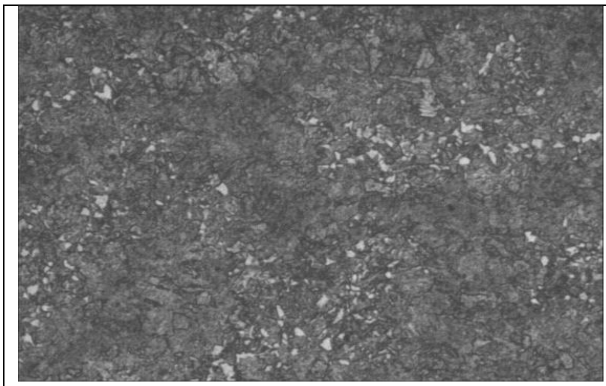
Sample (Ø390 X 265 Lmm)	Hardness after hardening at 860°C (BHN)	Hardness after tempering at 655°C (BHN)	Yield strength (MPa)
B	326,331,311	197,212,204	L = 488
			T = 503
			R= 463

Tensile Strength (MPa)	Elongation (%)	Reduction Area (%)	Impact (Charpy V notch) Temp – 45°C (J)	Avg
693	29.08	69.038	105,58,78	80.33
684	29.02	60.068	12,83,38	44.33
665	25.14	59.375	32,84,29	48.33

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

Microstructure Analysis after tempering

Figure 6: Microstructure of Tempered Sample A (tempered martensite & Ferrite, Etchant 2%Nital.



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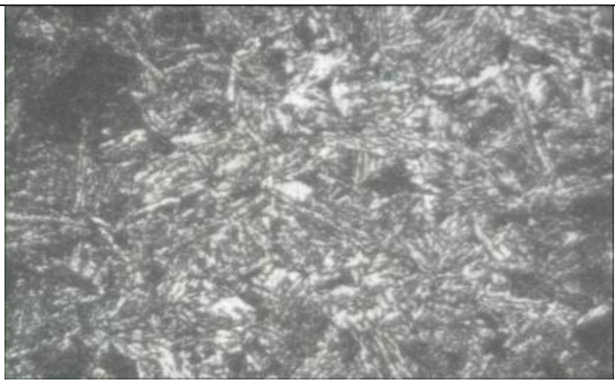

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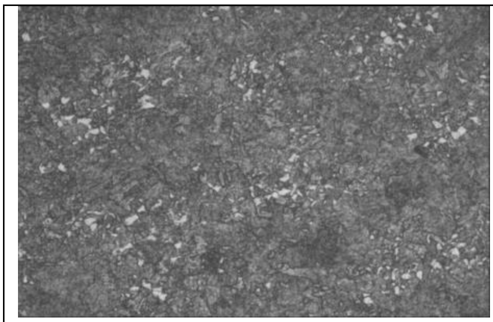
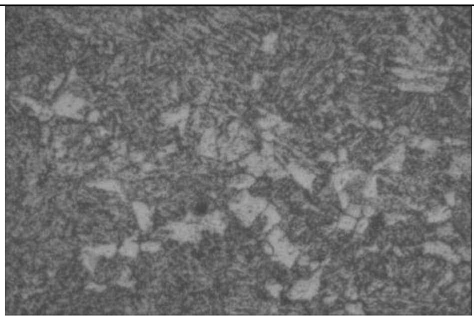
Micro analysis after tempering as below of Sample B:

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

	
100 X	400 X

DISCUSSIONS

The mechanical properties of Samples A and B are strongly influenced by their respective cooling rates during quenching. Sample A, with a higher cooling rate of 1.18 °C/s, exhibited higher hardness (~232 BHN) and superior strength, with yield strength up to 627 MPa and tensile strength up to 788 MPa. In contrast, Sample B, with a lower cooling rate of 0.64 °C/s, showed reduced hardness (~204 BHN) and lower strength values. However, Sample B demonstrated relatively higher ductility, as indicated by increased elongation and reduction in area.

Microstructural examination of both samples revealed the presence of tempered martensite along with ferrite. The higher cooling rate in Sample A restricted diffusion and retained a finer tempered martensitic structure, resulting in improved strength and hardness. Conversely, the lower cooling rate in Sample B promoted greater ferrite formation and coarsening of the microstructure during tempering, leading to reduced hardness and enhanced ductility.

Furthermore, variations in impact toughness along longitudinal, transverse, and radial directions can be attributed to non-uniform cooling and section thickness effects. These results highlight that cooling rate plays a crucial role in controlling microstructural evolution and consequently governs the balance between strength and ductility in the material.

CONCLUSIONS

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

Tempering temperature significantly affects the mechanical properties of AISI 4130 steel, where lower tempering (565 °C) provides higher strength and hardness, while higher tempering (655 °C) improves ductility and softens the microstructure.

Both conditions exhibit tempered martensite with ferrite, confirming a strength–ductility trade-off governed by tempering temperature.

REFRENCES

1. ASM Handbook volume 1 Properties & selection Irons steels & High performance alloys
2. ASM Handbook Volume 14 – Forming & Forging.
3. 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).

4. 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.
5. 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.
6. ASM Handbook, Volume 4: Heat Treating
7. Heat treatment - Principles & Techniques by T.V. Rajan
8. Metallographic Handbook by George F. Vander Voort.
9. Microscale & Macroscale Techniques in the Organic Laboratory by Mayo et al.
10. Physical metallurgy by Vijendra Singh.
11. Steels: Heat Treatment & Processing Principles by George Krauss