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INVESTIGATION OF TEMPERATURES AND HOLDING TIMES ON HIGH-STRENGTH LOW-ALLOY STEEL FOR TANK TRACK LINKS

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Abstract. In Indonesia, the reliance on foreign countries for military components persists, including tank track links which are crucial for combat vehicles. These components require mechanical properties such as wear resistance and toughness to ensure high safety standards. High Strength Low Alloy (HSLA) steel is used, necessitating precise composition and appropriate heat treatment processes. This study varied compositions and heat treatments to achieve desired properties, producing prototypes with five predetermined compositions. The heat treatment process involves initially heating the samples to 860°C for 30 minutes for uniformity, followed by various treatments including quenching in oil, normalizing, and multiple cycles of quenching with tempering at different temperatures and durations to refine microstructure and adjust hardness of the alloy. Results showed optimal mechanical properties in composition no. 4 after normalizing with a blower, achieving a hardness of 31 HRC. This research aimed to optimize mechanical performance during operational conditions through variations in temperatures and holding times.
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Keywords : Tracklink tank, High Strength Low Alloy, Heat Treatment,

1. INTRODUCTION

The High Strength Low Alloy (HSLA) steel is a specialized alloy designed to enhance mechanical properties and corrosion resistance compared to low-carbon steels [1], [2]. Unlike steels with specific chemical compositions, HSLA steel focuses primarily on optimizing its mechanical characteristics [3]. Typically containing carbon levels ranging from 0.05% to 0.25%, HSLA steel exhibits excellent formability and weldability [4]-[6]. It incorporates additional alloying elements such as manganese (up to 2%), along with trace amounts of copper, nickel, niobium, nitrogen, vanadium, chromium, molybdenum, titanium, aluminum, and calcium. These elements are carefully chosen to achieve a microstructure of ferrite and pearlite, with finely dispersed carbides embedded within the ferritic matrix [7]-[8]. The reduction of pearlite phase through grain refinement enhances the material's strength, with an increase in yield strength ranging from 250 to 590 megapascals (36,000 to 86,000 psi) [9].

Due to its high strength and toughness, HSLA steel requires approximately 25-30% more energy for shaping compared to low-carbon steel [10], [11]. The addition of elements such as copper, silicon, nickel, chromium, and phosphorus aims to improve the alloy's corrosion resistance [12], [13]. Conversely, zirconium and calcium are included to mitigate sulfide impurities, crucial for enhancing formability in this sensitive type of steel [14]. The distinctive properties of formability and impact strength are evident in longitudinal and transverse grain testing, where bending often induces fractures near grain boundaries under tensile stress. Therefore, controlling sulfide content is crucial to maintain the mechanical properties of HSLA steel throughout its service life [15], [16].

HSLA steel represents a significant advancement in metallurgical engineering, leveraging precise alloy design and processing techniques to achieve a balanced combination of strength, formability, and corrosion resistance [17]-[20]. However, despite the well-documented benefits of HSLA steel, there is a gap in understanding how different temperatures, and holding times impact the mechanical properties of HSLA steel, particularly for critical applications such as tank track links. Optimizing these parameters is crucial because tank track links must withstand extreme operational conditions, requiring precise control over the steels hardness. Understanding these properties not only facilitates the development of durable structural components but also underscores the importance of optimizing alloy composition and production methods to meet stringent performance requirements in various industrial applications. This study aims to fill this gap by systematically investigating the effects of temperatures and holding times on the mechanical properties of HSLA steel, thereby enhancing its performance and durability in military applications.

2. METHODS

The research Reverse material analysis involves the systematic evaluation and modification of materials to achieve altered properties while maintaining the base material's structural integrity. The goal of this approach is to enhance specific material properties to meet desired functional requirements. The dimensions of the material are shown in Figure 1. In this study, High Strength Low Alloy (HSLA) steel serves as the base material. Y-block samples, conforming to JIS G5502 standards, are cast and subsequently sectioned into smaller pieces for ease of handling during heat treatment. Samples are specifically taken from the edges, critical for evaluating performance in tank track applications. The composition of the HSLA steel alloy was examined using a spectrometer to ensure accurate determination of the elemental makeup. This analysis allowed for precise measurement of key elements, such as carbon, manganese, chromium, silicon, and others, which are essential for understanding how the alloy's composition affects its properties and performance.

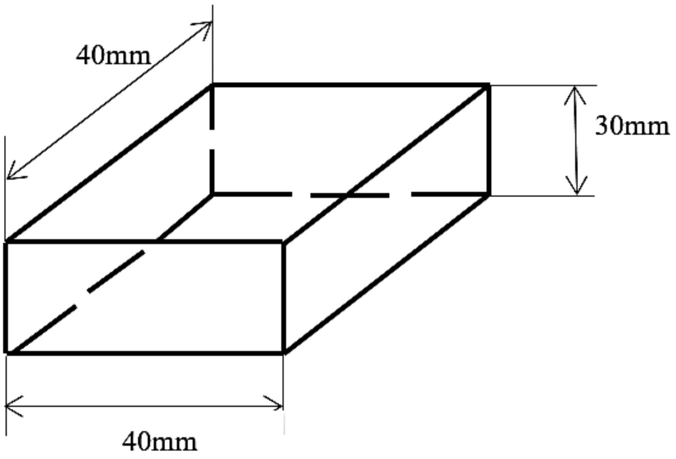


Figure 1. Dimensions of the test specimen

The heat treatment begins with a solution treatment phase at 860°C, with a 30-minute holding period to ensure uniformity. Following this, each of the five compositions undergoes a series of heat treatment processes including quenching (using oil), normalizing, quenching + tempering 600oC 30 minute, quenching + tempering 600°C 60 minute, quenching + tempering 400°C 30 minute, quenching + tempering 400°C 60 minute . Quenching using oil is applied to rapidly cool the material and create a harder microstructure. Normalizing performed to refine the grain structure and relieve internal stresses. Tempering is used to optimize hardness while retaining sufficient toughness for operational durability. These processes are essential for refining the microstructure and adjusting mechanical properties such as hardness and wear resistance. Post-heat treatment, the materials undergo comprehensive laboratory testing, encompassing hardness testing, microstructure analysis, and wear testing to validate the effectiveness of the heat treatment processes and assess the suitability of the materials for tank track applications.This methodological approach ensures systematic evaluation and enhancement of HSLA steel properties through controlled heat treatments and rigorous laboratory testing, aiming to optimize material performance in demanding operational conditions.

3. RESULTS AND DISCUSSION

3.1 Chemical Composition Testing

The chemical composition of the high-strength low-alloy (HSLA) steel samples, obtained through the reverse material process following JIS G 511 standards and induction furnace casting, was meticulously analyzed. Table 1 summarizes the results of the chemical composition testing, showcasing the percentage composition of various key elements crucial for the heat treatment processes and overall material performance.The composition analysis reveals significant levels of carbon (C), manganese (Mn), chromium (Cr), silicon (Si), phosphorus (P), sulfur (S), copper (Cu), nickel (Ni), molybdenum (Mo), and predominantly iron (Fe) as the base element (Table 1). These elements are strategically alloyed to impart specific mechanical properties, such as strength, toughness, and corrosion resistance, essential for the intended application in tank track components.

The observed chemical composition aligns with targeted specifications for HSLA steel, ensuring optimal properties required for heat treatment processes. Carbon content influences hardness and strength, while manganese contributes to toughness and hardenability during quenching. Chromium enhances corrosion resistance and hardenability, crucial for maintaining structural integrity under harsh operational conditions. Silicon improves strength and elasticity, while phosphorus and sulfur levels are controlled to enhance machinability and reduce brittleness.The results underscore the importance of precise alloying and casting processes in achieving desired material properties. Future studies will focus on correlating these compositions with mechanical testing results to further validate the effectiveness of the chosen alloy designs for enhancing the performance and durability of HSLA steel in military applications.

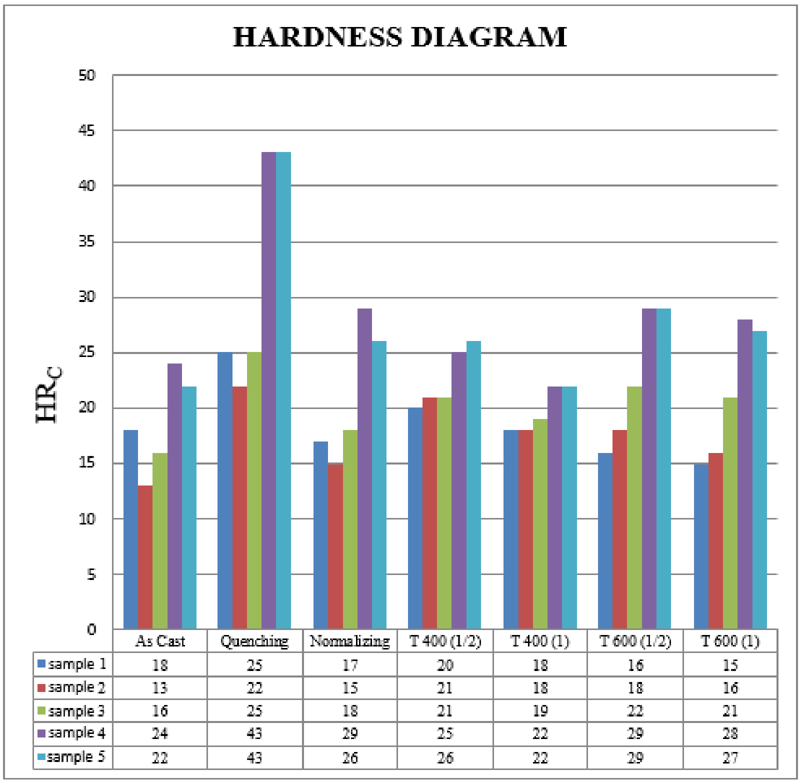
Table 1. Results of Chemical Composition Testing

Chemical Element	C	Mn	Cr	Si	P	S	Cu	Ni	Mo	Fe
Test Result (%)	0.34	0.79	0.969	0.486	0.011	0.022	0.035	0.045	0.328	Balance

3.2 Hardness Testing

Five compositions of hypo eutectoid steel underwent heat treatment processes. Heating was conducted at 860°C, reaching the A3 + 100°C temperature, where austenite phase (γ) is obtained. Heating at the austenite temperature aims to stabilize the phase uniformly as austenite (γ), ensuring comprehensive phase transformation. Following heating to 860°C, a holding time was applied to uniformly form austenite (γ), as the holding time aims to homogenize phases for predictable phase formation during cooling.

Cooling was achieved using oil as the medium, and the cooling medium significantly impacts hardness results. The hardness results for each composition are as follows: the highest average hardness of 43 HRC was achieved in the oil quenching process. The highest hardness average for as-cast material was 24 HRC. Normalizing yielded the highest average hardness of 29 HRC. Tempering at 400°C for 30 minutes resulted in the highest hardness data for composition number 5 at 26 HRC. Tempering at 400°C for 60 minutes showed composition number 4 with the highest hardness at 25 HRC. Tempering at 600°C for 30 minutes resulted in compositions number 4 and 5 achieving the highest hardness of 29 HRC



	As Cast	Quenching	Normalizing	T 400 (1/2)	T 400 (1)	T 600 (1/2)	T 600 (1)
sample 1	18	25	17	20	18	16	15
sample 2	13	22	15	21	18	18	16
sample 3	16	25	18	21	19	22	21
sample 4	24	43	29	25	22	29	28
sample 5	22	43	26	26	22	29	27

Figure 2. Hardness Data After Heat Treatment Process

These results highlight the critical role of tempering conditions in influencing the hardness characteristics of the material. Specifically, the tempering process at 600°C for 60 minutes effectively adjusted the hardness of sample 4 to approximate the desired hardness standard of 28 HRC seen in the imported tank tracklink (Figure 2.). This finding underscores the importance of precise heat treatment parameters in achieving optimal mechanical properties for tank components. Further research into the microstructural changes induced by varying tempering durations and temperatures could provide additional insights into enhancing the performance and durability of tank tracklinks

3.3 Metallographic Testing

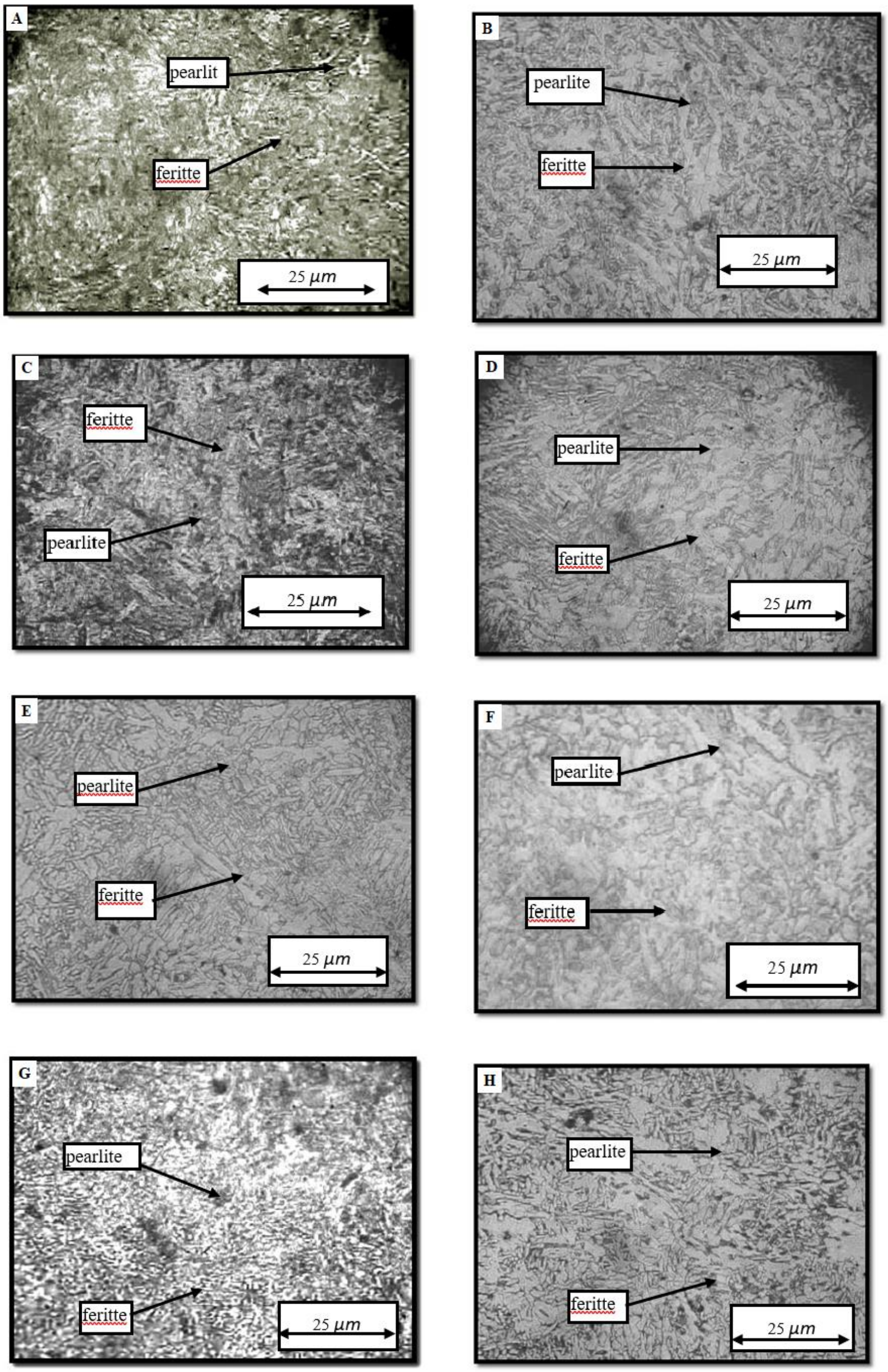


Figure 3. Microstructure with 3% nital etching and 400x magnification under the conditions: (a) as cast, hardness 24 HRC, (b) quenching, hardness 43 HRC, (c) tempering 400°C for 60 minutes, hardness 22 HRC, (d) normalizing, hardness 29 HRC, (e) tempering 400°C for 30 minutes, hardness 25 HRC, (f) tempering 600°C for 60 minutes, hardness 28 HRC, (g) normalizing with blower, hardness 31 HRC, (h) tempering 600°C for 30 minutes, hardness 29 HRC

Analysis of metallographic testing data across the five compositions confirms the presence of ferrite and pearlite phases in all material configurations, differing primarily in their matrix compositions and the granularity of their constituent grains. Materials characterized by a ferrite and pearlite matrix generally exhibit lower hardness values, a consequence of the soft nature inherent to ferrite. Hence, materials featuring a ferrite matrix typically demonstrate lower overall hardness. Conversely, materials featuring a pearlite matrix tend to manifest higher hardness values compared to their ferrite matrix counterparts, due to the inherent hardness of pearlite itself. Notably, materials with finer grain structures demonstrate superior strength characteristics, particularly evident in specimens subjected to the quenching process. This phenomenon is largely attributed to the elevated manganese content, which acts as a catalyst for pearlite formation, thereby promoting the development of finer rains during the pearlite transformation process.

4. CONCLUSION

From the results and discussions of this study, several conclusions can be drawn. Alloying elements play a crucial role in the physical and mechanical properties of HSLA (High Strength Low Alloy) steels, particularly Cr, Mo, C, Mn, Cu, and Ni. Therefore, it is necessary to conduct a composition test to confirm that the steel falls within the JIS G511 standard. The highest average hardness value of 29 HRC was obtained from samples subjected to normalizing, while the lowest average hardness value of 13 HRC was found in as-cast samples. Microstructural observations revealed martensitic and residual austenitic phases in as-cast specimens, whereas bainitic phases were observed after normalizing. Among the samples tested as potential materials for tank track links, sample number 4 showed the most promising hardness improvement trend.Metallographic analysis showed that specimens with the highest hardness values exhibited a pearlitic microstructure. Specimens with the lowest hardness values displayed a ferrite and pearlite matrix microstructure. Future research should focus on detailed microstructural analysis and mechanical testing to further optimize the performance and durability of HSLA steel in military applications.

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