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Investigation of Vickers Hardness in Hardened Scrap Automotive Spring Steel

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ABSTRACT

The objective of this study is to investigate the effect of hardening temperature on the surface hardness of high carbon steel. The research was conducted experimentally in a laboratory setting using descriptive statistical analysis. The material used was high carbon steel with a carbon content of 0.465%. Three hardened test samples were subjected to Vickers hardness testing, with five indentations measured on the upper, middle, and lower sections of each sample. One additional sample was left untreated as a control. The hardening process involved heating the samples to varying austenitizing temperatures of 600°C, 700°C, and 800°C, followed by quenching in water. The findings of this study aim to reveal the hardness characteristics of recycled leaf spring steel after undergoing different hardening treatments.

1. Introduction

With the rapid advancement of the industrial sector, the demand for metal elements continues to increase. Metals play a dominant role as raw materials in the manufacturing of various tools and equipment. Commonly used metals include iron (Fe), as well as non-ferrous metals such as aluminum (Al), copper (Cu), chromium (Cr), and nickel (Ni). Among these, iron or steel is the most widely used metal in industrial production due to its availability and ability to meet the needs of society. The public demands tools that are strong, hard, and durable. In response, the industrial world must ensure that the products it produces meet these criteria [1-4].

Steel, while widely used, has relatively poor wear and friction resistance. Therefore, it is necessary to improve its mechanical surface properties, especially hardness and microstructure, which are closely related to wear resistance. Hardness is a measure of a material's resistance to deformation caused by an external object [5]. One way to enhance the properties of metals is through heat treatment. Heat treatment is a process involving controlled heating and cooling to achieve specific material properties [6, 7].

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The purpose of heat treatment is to improve various material characteristics within their potential range, such as increasing strength and hardness, reducing residual stress, softening the material, restoring properties altered by prior working, and refining the grain structure, which influences ductility and other traits [8].

Several common heat treatment methods include hardening, annealing, and tempering. Among these, hardening is frequently used to improve a material's strength and hardness. Hardening is a strengthening process that relies on phase separation and involves the dispersion of hard phases in a ductile matrix. This method enhances surface hardness, strength, and the wear resistance of steel. A key advantage of hardening is that it does not require the addition of external carbon sources—quenching alone is sufficient. Furthermore, hardening can be applied selectively to specific parts of a component depending on its function [9].

Several factors influence the effectiveness of the hardening process, including the material's carbon content, temperature, cooling medium, and holding time. Carbon content helps determine the critical temperature during hardening, while temperature plays a crucial role in dissolving carbon into the austenite phase. The resulting surface hardness depends on the amount of martensite formed. After heating, the material is quenched to promote the formation of martensite on the surface, creating a hard outer layer with a tough or ductile core [10]. Iron and steel contribute to human welfare by serving as key materials in construction, industrial equipment, and machine tools such as drill bits, cutting tools, and milling cutters.

Based on this background, the issue identified in this study is the suboptimal quality and consistency of materials produced by industry. One contributing factor is the heat treatment process. The hardening method is chosen due to its effectiveness in increasing material hardness. This research aims to investigate the effect of hardening on the hardness of scrap leaf spring steel and provide a reference for future studies in heat treatment, as well as serve as educational material in the field of material science and testing.

2. Methodology

This research was conducted at the Mechanical Engineering Department of Politeknik Negeri Banjarmasin, South Kalimantan, utilizing a Vickers hardness testing machine and an electric furnace. The hardening process was applied to metal samples to enhance wear resistance and increase surface hardness or improve fatigue strength. Hardening is a type of heat treatment in which steel is heated to a temperature above its critical point and held for a specific period before being rapidly cooled by quenching in water, oil, or a salt solution, depending on the type of steel. This rapid cooling transforms the austenite into hard martensite. The heating temperature, holding time, and cooling rate in the hardening process largely depend on the steel's chemical composition.

Figure 1. Hardness test specimen.

Figure 2. Quenching media used in the hardening process.

An experimental method was employed in this research, starting from material selection to the hardening process and hardness testing. The hardness of the samples was evaluated using the Vickers hardness testing method. The results obtained were then analyzed by examining the relationship between hardening temperature and surface hardness through graphical representation.

3. Results and Discussion

The results of the Vickers hardness test on high-carbon scrap leaf spring steel subjected to hardening at various temperatures (600°C, 700°C, and 800°C) are summarized in Table 1 and visualized in Figure 1. The hardness values were obtained using a 30 kgf load and measured at multiple points across the specimen surface. Each sample underwent five indentations to ensure data reliability, and the average hardness was calculated.

Table 1. Vickers hardness test results at different hardening temperatures

No	Temperature (°C)	d_1 (mm)	d_2 (mm)	Average D (mm)	Load (kgf)	Vickers Hardness (HV)
1	600	0.31	0.29	0.325	30	526.5
2	600	0.31	0.28	0.295	30	639.1
3	600	0.33	0.28	0.305	30	597.9
4	600	0.34	0.32	0.330	30	510.7
5	600	0.30	0.29	0.295	30	639.1
					Average	582.6
1	700	0.29	0.28	0.285	30	684.7
2	700	0.35	0.34	0.335	30	330.5
3	700	0.30	0.31	0.305	30	510.7
4	700	0.35	0.31	0.310	30	514.3
5	700	0.29	0.29	0.320	30	720.3
					Average	552.1
1	800	0.34	0.29	0.315	30	560.5
2	800	0.87	0.77	0.820	30	350.5
3	800	0.87	0.77	0.815	30	82.7
4	800	0.65	0.58	0.615	30	114.7
5	800	0.33	0.29	0.310	30	578.7
					Average	393.3

At a hardening temperature of 600°C, the material achieved the highest average hardness of 582.6 HV, with individual values ranging from 510.7 HV to 639.1 HV. This indicates that at this temperature, the formation of martensitic structure was optimal, resulting in a significant increase in surface hardness [11, 12]. The temperature was sufficiently high to allow complete austenitization, while still low enough to prevent grain coarsening, which contributes to higher hardness.

When the hardening temperature was increased to 700°C, the average hardness dropped slightly to 552.1 HV. Although still relatively high, the slight decrease suggests the beginning of grain growth, which reduces hardness. However, the hardness values still indicate a predominance of martensitic microstructure. Notably, individual hardness readings at this temperature showed a wider variation, suggesting less consistency in martensite formation across the samples.

At 800°C, a significant decrease in average hardness was observed, falling to 393.3 HV. Some individual readings dropped as low as 82.7 HV, indicating insufficient martensitic transformation and possibly the formation of softer phases such as coarse pearlite or retained austenite. This is likely due to overheating and excessive grain growth, which reduces the steel's ability to form a fine, hard martensitic structure upon quenching. The inconsistency in hardness values at this temperature further highlights the instability of microstructural transformation under excessive heat [13-15].

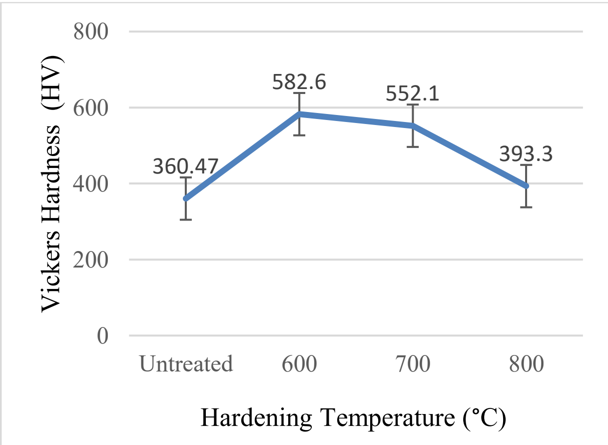

Figure 1. Graph of vickers hardness values as a function of hardening temperature

The findings clearly demonstrate that temperature is a critical parameter in the hardening process. While 600°C provides optimal conditions for surface hardening of scrap leaf spring steel, increasing the temperature beyond this point can negatively impact the resulting mechanical properties.

These results align with established metallurgical principles, where optimal austenitizing and rapid quenching favor martensite formation, but excessive temperature leads to degradation in microstructure and mechanical performance.

4. Conclusions

Based on the experimental investigation of the hardening process on scrap leaf spring steel using varying temperatures, the following conclusions can be drawn:

1. Hardening temperature significantly influences surface hardness. The highest average Vickers hardness value was achieved at 600°C (582.6 HV), indicating optimal martensite formation.
2. Increasing the temperature to 700°C resulted in a slight decrease in average hardness (552.1 HV), likely due to initial grain coarsening.
3. At 800°C, the average hardness dropped sharply to 393.3 HV, with wide variation in measurements, suggesting over-austenitization and unstable microstructural transformation.
4. The most effective hardening temperature for enhancing the surface hardness of scrap leaf spring steel is 600°C, which balances carbon diffusion and martensite transformation without degrading the material's structure.

These findings demonstrate that proper control of hardening parameters—particularly temperature—is essential in optimizing the mechanical properties of recycled high-carbon steel components.

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