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Effect of Annealing Temperature on Mechanical Properties of AISI 1045 Carbon Steel

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ABSTRACT

Research investigating the influence of annealing temperature variations on the mechanical properties of AISI 1045 carbon steel has been undertaken, with annealing temperatures systematically varied. The specimens utilized in this investigation were of standardized dimensions, possessing a diameter of 20 mm and a length of 30 mm. Given the pivotal role of AISI 1045 steel within the manufacturing sector, substantial attention has been directed towards its research and development. This study aims to scrutinize the resultant microstructure following annealing at distinct temperatures, ascertain the effect of annealing temperature on the hardness characteristics of AISI 1045 steel, and evaluate its corrosion resistance. The specimens underwent heating in a controlled furnace for 1 hour, encompassing temperatures of 250°C, 500°C, 750°C, and 1000°C, followed by gradual cooling to ambient conditions. Subsequent analyses encompassed hardness assessments, corrosion rate evaluations, and microstructural investigations employing a Scanning Electron Microscope (SEM). The findings revealed a notable hardness of 119.3 HRC achieved at 500°C, alongside a corrosion rate of 0.0014 mm/y recorded at 1000°C. These results, bolstered by SEM observations, underscore the favorable mechanical properties exhibited by AISI 1045 carbon steel after the annealing process.

Keywords: AISI 1045 Carbon Steel, Annealing Process, Mechanical Properties, Temperature

ABSTRAK

Penelitian mengenai pengaruh variasi suhu pemanasan ulang terhadap sifat mekanik baja karbon AISI 1045 telah dilakukan dengan memvariasikan suhu pemanasan ulang. Sampel yang digunakan dalam penelitian ini memiliki diameter 20 mm dan panjang 30 mm. Mengingat pentingnya baja AISI 1045 dalam industri manufaktur, telah dilakukan penelitian dan pengembangan yang luas. Studi ini bertujuan untuk menganalisis mikrostruktur yang terbentuk selama proses pemanasan ulang pada suhu yang berbeda, untuk menentukan dampak suhu pemanasan ulang terhadap nilai kekerasan baja AISI 1045, dan untuk mengevaluasi laju korosi baja tersebut. Sampel dipanaskan dalam tungku selama 1 jam pada suhu 250°C, 500°C, 750°C, dan 1000°C. Setelah dikeluarkan dari tungku, sampel dikembalikan ke suhu ruang. Selanjutnya, dilakukan uji kekerasan, uji laju korosi, dan pengamatan mikrostruktur menggunakan Mikroskop Elektron Penyebaran (SEM). Hasil menunjukkan bahwa kekerasan sebesar 119,3 HRC dapat dicapai pada suhu 500°C, dan laju korosi sebesar 0,0014 mm/tahun dapat dicapai pada suhu 1000°C. Nilai-nilai yang diperoleh dari uji tersebut, didukung oleh pengamatan SEM, menunjukkan bahwa baja karbon AISI 1045 menunjukkan sifat mekanik yang baik setelah proses pemanasan ulang.

Kata kunci: Baja Karbon AISI 1045, Proses Annealing, Sifat Mekanik, Temperatur

1. Introduction

The metal industry is developing rapidly, primarily due to several factors that specifically support process and materials engineering. All human needs originate from metal elements, which is why there is a continuous effort to improve the physical and mechanical properties of metals through heat treatment processes. These processes are useful for enhancing the properties of metals, such as steel [1].

Steel is a metal widely used in production and as a raw material in various industries, including carbon steel. Carbon steel is one of the types made from a mixture of iron and carbon as its main components [2]. Carbon steel typically has a carbon percentage ranging from 0.12% to 2.0%. This type of steel is extensively used in the metal industry, heavy equipment industry, transportation industry, and many others [3].

Society and industrial companies are striving to improve metals' physical and mechanical properties to meet their desired requirements. One way to enhance and improve these properties is through heat treatment, crucial in modifying metal properties to suit specific needs [4]. Heat treatment is a procedure that encompasses a combination of heating and cooling of metals or similar alloys in a solid state, aimed at obtaining specific desired properties [5], [6]. In heat treatment, to achieve proper results, the cooling rate and the final temperature influence the changes in the microstructure within the metal [7]–[9]. This is because the microstructure, after being subjected to the heat treatment process, greatly determines the properties of the metal.

The heat treatment aims to produce hard, soft, flexible metals capable of improving machinery and eliminating residual stress. Heat treatment is commonly used to increase the hardness of a material, but it can be used to modify specific properties for manufacturing purposes, such as improving machinability, enhancing ductility, and restoring elasticity after cold or even hot working. It supports manufacturing characteristics and can enhance material performance by improving certain metal properties after heat treatment [10].

Rumayar [11] conducted research to assess the effect of the annealing process on the results of SMAW welding of ASTM A36 steel and its physical and mechanical properties. The results obtained through the annealing process on ASTM A36 steel showed that the material's load-bearing capacity had the highest tensile strength at 650°C, while the lowest tensile strength was at 550°C and 750°C. This is due to the ideal heat input and cooling rate at these temperatures, particularly at 650°C.

The softening process, such as annealing, is a heat treatment process to obtain coarse but soft pearlite. It entails heating the metal to the austenitizing temperature and cooling it slowly in a furnace. This aim is to enlarge the grain size and enhance the machinability of the metal [12]. The annealing process is also carried out to increase ductility and reduce internal stresses that cause the metal to become brittle [13], [14].

This research aims to investigate how varying temperatures in the annealing process affect the mechanical properties of AISI 1045 carbon steel, including aspects such as ductility, strength, hardness, and toughness. This research is expected to improve the mechanical properties and components of the metal, such as ductility, strength, hardness, toughness, and more. In addition to enhancing wear resistance, it aims to reduce the need for forming forces and to prepare the metal according to processing requirements.

2. Method

This research is an experimental study. The sample preparation process is conducted in the Physical Metallurgy Laboratory of the Politeknik Teknologi Kimia Industri (PTKI), and the characterization of the mechanical properties and microstructure of AISI 1045 steel, which has undergone the annealing process, is carried out in the Integrated Research Laboratory of Politeknik Teknologi Kimia Industri (PTKI). The material used was medium carbon steel AISI 1045.

2.1. Specimen Preparation

AISI 1045 steel was cut into 15 pieces, each with a length of 30 mm and a diameter of 20 mm. Both ends of the material were evened out using sandpaper. The material was cleaned of rust, oil, and other particles adhering to the surface to ensure they did not affect the annealing process results.

2.2. Annealing Heat Treatment Process

The cut specimens measuring 30 mm in length and 20 mm in diameter were inserted into a heating furnace. The annealing process was performed by heating five workpieces at varying temperatures without heat treatment (original), 250°C, 500°C, 750°C, and 1000°C, and they were maintained at these temperatures for a holding time of 1 hour. After annealing, the specimens were eliminated from the heating furnace and conditioned to cool down gradually using air cooling. Once cooled, the specimens underwent physical property testing (density test) and mechanical property testing (hardness test and corrosion rate test), as well as microstructure observation using Scanning Electron Microscope (SEM).

3. Results and Discussion

3.1. Density Testing

The density test is a physical property that indicates the ratio of an object's mass to its volume or the mass of a substance per unit volume. The relationship between the density of AISI 1045 steel and the varying annealing temperatures can be illustrated in Figure 1.

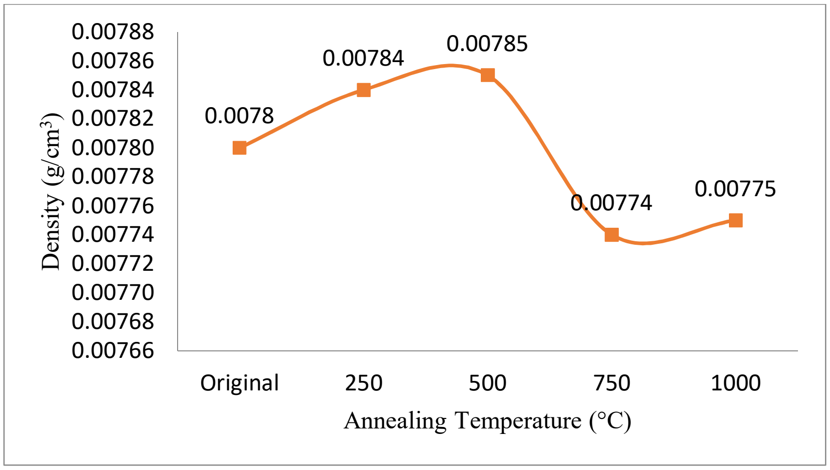

Figure 1. Density of AISI steel after annealing.

Figure 1 illustrates the density achieved by medium carbon AISI 1045 Steel following annealing, with a 60-minute holding time at various temperatures: Original (without treatment) at 0.00780 g/cm³, 250°C at 0.00784 g/cm³, 500°C at 0.00785 g/cm³, 750°C at 0.00774 g/cm³, and 1000°C at 0.00775 g/cm³. The highest density is observed at 500°C, registering 0.00785, while the lowest is recorded at 750°C (0.00774 g/cm³). Increasing the annealing temperature can enhance the density value of AISI 1045 carbon steel, reaching its peak at 500°C. However, further temperature escalation can decrease the density value of AISI 1045 steel [15].

3.2. Rockwell Hardness Test

The hardness test is a mechanical property that represents the hardness value and can illustrate the acceptance strength of steel. The hardness test will produce a hardness value in Rockwell Hardness Scale C (HRC) using an Equotip Portable Rockwell Hardness Tester. This value is compared with the tensile strength obtained from a tensile test using a universal testing machine. In this research, hardness testing is performed on the middle and both edges of the sample. These testing points are divided into points A, B, and C. Testing the edges and the middle is intended to determine the differences in properties and the tolerable capacity of the steel profile sample. Additionally, this approach can increase the accuracy of the hardness value by having multiple testing points. The relationship between the hardness of AISI 1045 Steel and the annealing temperature variations can be illustrated in Figure 2.

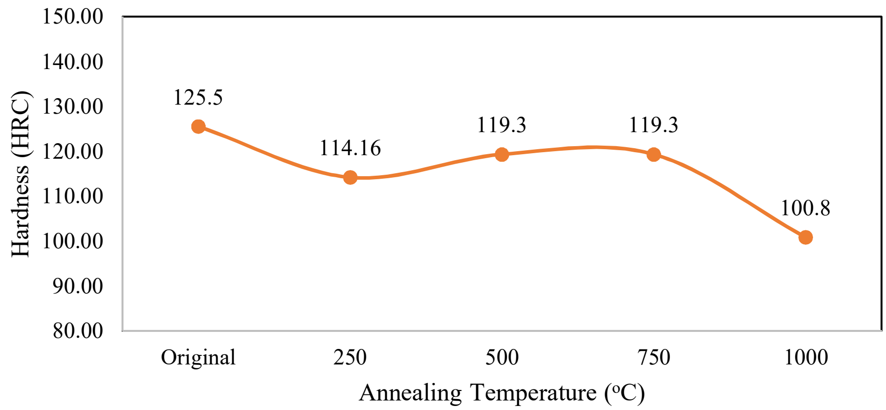

Figure 2. The hardness of AISI steel after annealing.

Figure 2 presents the hardness of AISI 1045 steel resulting from variations in annealing temperature, with a 60-minute holding time. The average hardness values obtained are as follows: Original (untreated) at 125.5 HRC, 250°C at 114.16 HRC, 500°C at 119.3 HRC, 750°C at 107.3 HRC, and 1000°C at 100.8 HRC. The highest hardness post-annealing process is attained at 500°C, registering 119.3 HRC, while the lowest hardness is observed at 1000°C, measuring 100.8 HRC, as reported by Al Faris and Rasyid [16].

This research data indicates that the material had undergone previous heat treatment, resulting in annealing. The mechanical property changes tend to soften the material, deviating from the expected outcome because testing can increase the material's hardness level. However, as noted by Wicaksono the material becomes brittle and hard, reducing the hardness level, although not excessively [17].

3.3. Corrosion Rate Test

Figure 3 illustrates the corrosion rate of AISI 1045 steel under different annealing temperatures after undergoing corrosion tests. This test aims to assess the impact of temperature and cooling media during the heat treatment on the extent of corrosion.

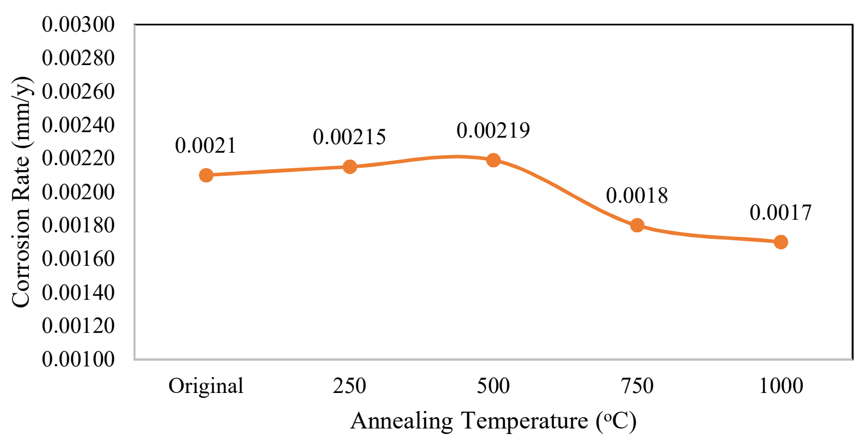

Figure 3. Corrosion rate of AISI steel after annealing.

The methodology used for the corrosion test involves immersing the material in an H_2SO_4 solution for 22 hours. The corrosion rate is calculated using the weight loss method. Data from the specimen after the corrosion test on AISI 1045 steel, which has not undergone heat treatment (raw material), is used as a baseline for comparing the corrosion rate of materials subjected to heat treatment.

Figure 3 illustrates the corrosion rate of AISI 1045 steel resulting from variations in annealing temperature, with a 60-minute holding time. The corrosion rates obtained are as follows: original (untreated) at 0.0021 mm/y, 250°C at 0.00215 mm/y, 500°C at 0.00219 mm/y, 750°C at 0.0018 mm/y, and 1000°C at 0.0017 mm/y. The highest corrosion rate post-annealing process is observed at 500°C, measuring 0.00219 mm/y, while the lowest is at 1000°C, with a rate of 0.0017 mm/y. The annealing temperature significantly influences the corrosion rate of AISI 1045 steel. It is noted that higher annealing temperatures correspond to lower corrosion rates, as reported by Nugroho et al [18].

3.4. Microstructure Observation

Microstructure testing was conducted using SEM on AISI 1045 steel after annealingith temperature variations and a holding time of 60 minutes [19]. The results of SEM analysis on AISI 1045 carbon steel samples can be illustrated in Figure 4.

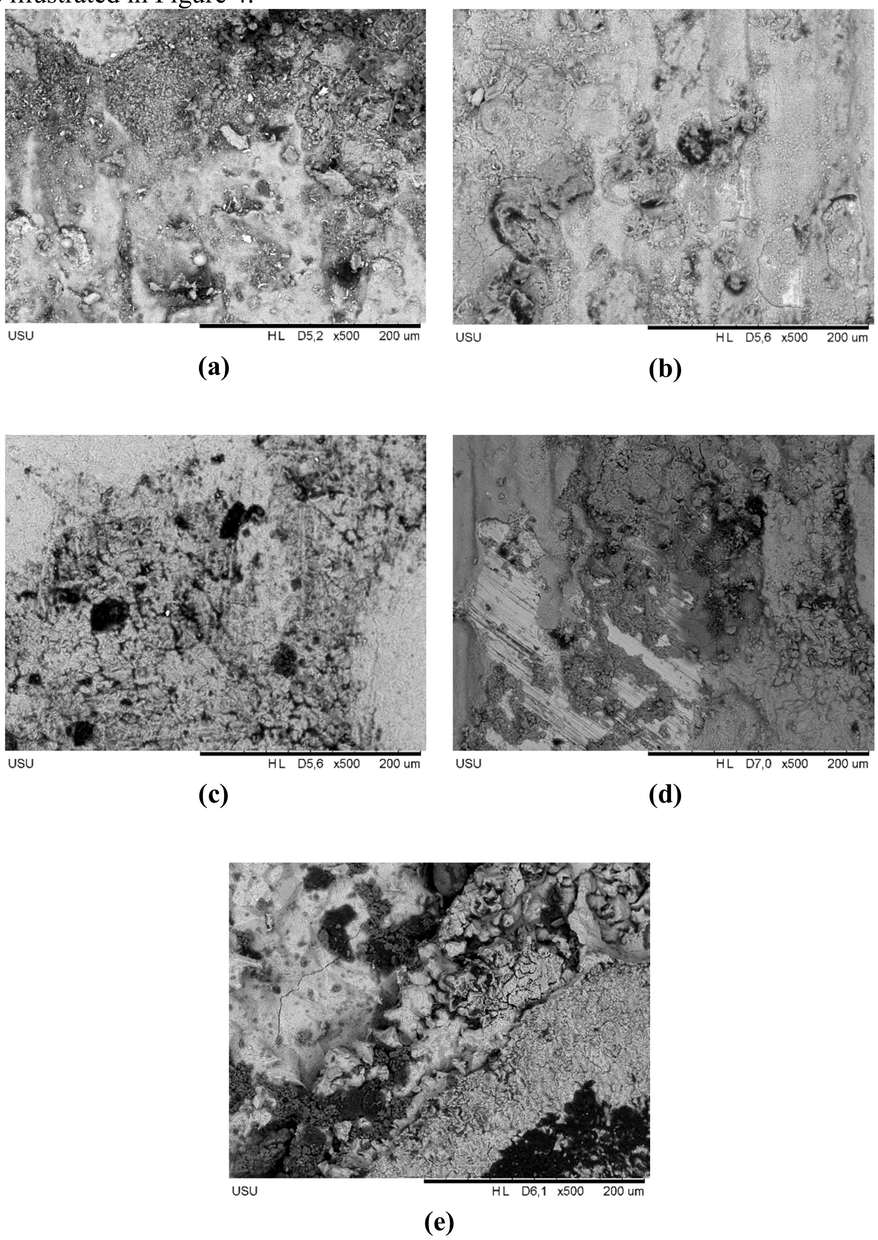

Figure 4. Results of SEM testing on AISI 1045 carbon steel with annealing temperature variations: (a) original (without treatment), (b) at 250°C, (c) at 500°C, (d) at 750°C, and (e) at 1000°C.

Figure 4 shows SEM morphology on AISI 1045 steel after the annealing process with a 500x magnification. It can be observed that the microstructure of the AISI 1045 steel, both before and after the Annealing process, exhibits differences. Figure 5 displays the results of the particle size distribution analysis of a sample of AISI 1045 carbon steel.

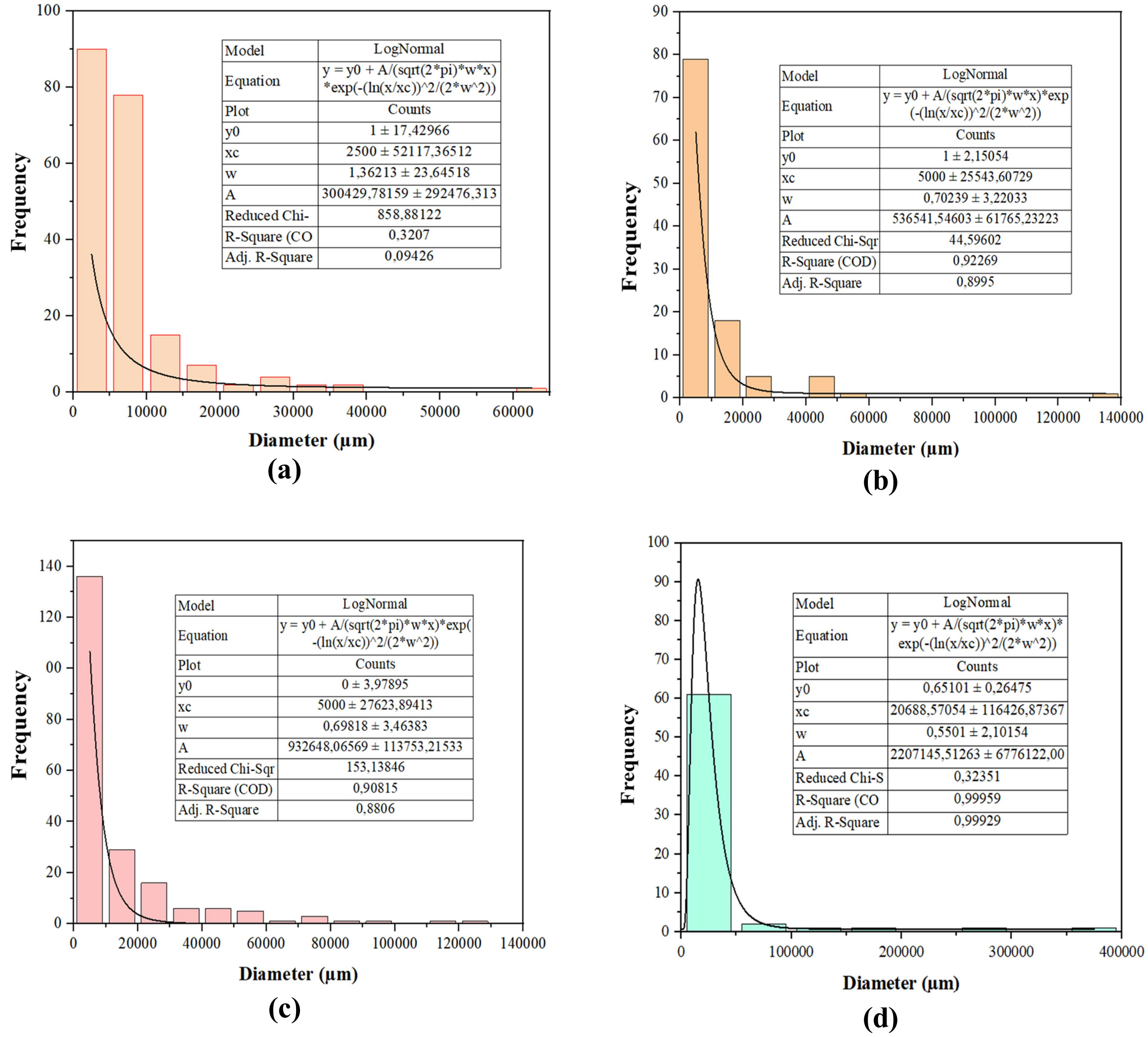

Figure 5. Particle size distribution of AISI 1045 carbon steel with annealing temperature variations: (a) original (without treatment), (b) at 250°C, (c) at 500°C, (d) at 750°C, and (e) at 1000°C.

Figure 5 showcases the particle sizes of AISI 1045 steel, determined through Image J and Origin Lab software analysis. The results reveal the average particle sizes as follows: for untreated Sample 1, 2500 ± 52117.36512 µm; for Sample 2 annealed at 250°C, 5000 ± 25543.60729 µm; for Sample 3 annealed at 500°C, 5000 ± 27623.89413 µm; for Sample 4 annealed at 750°C, 200688.57054 ± 116426.87367 µm; and for Sample 5 annealed at 1000°C, 33463.69351 ± 3960.75968 µm. Annealing effectively diminishes the particle size of AISI 1045 steel, with the most pronounced reduction observed in Sample 3, annealed at 500°C, where the optimum Adj R-Square value is 0.8806 µm [20].

4. Conclusion

In summary, our investigation into the effects of annealing temperature variation on the mechanical properties of AISI 1045 steel reveals significant impacts. We observed distinct hardness, corrosion rate, and microstructure alterations through systematic variation of annealing temperature and a consistent holding time of 60 minutes. Notably, increasing annealing temperature led to varying degrees of change in density, hardness, and corrosion rate, with optimal results achieved at specific temperatures. The density ranged from 0.00774 to 0.00785 g/cm³, hardness from 100.8 to 125.5 HRC, and corrosion rate from 0.0014 to 0.0032 mm/y. These findings, reinforced by SEM microstructure observations, underscore the pivotal role of annealing temperature in tailoring the mechanical properties of AISI 1045 steel. Our study highlights the importance of precise annealing control for achieving desired material characteristics in industrial applications.

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