

The Effect of Hardening Process on SKD 61 Material using Single Quenching and Double Quenching Techniques on Its Mechanical Properties

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Abstract

This study focuses on investigating the effects of single quenching and double quenching techniques on the mechanical properties of SKD 61 material, particularly in the context of bending strength and hardness measured using the Brinell hardness test. The research method involved heating SKD 61 specimens to 1000°C for 15 minutes, followed by cooling using oil and air as quenching media. The results showed that the single quenching technique with oil medium increased the bending strength from 406.89 to 435.84 N/mm² and the hardness from 255 to 315 HB. The single quenching technique using air increased the bending strength to 410.88 N/mm² and the hardness to 290 HB. Meanwhile, the double quenching technique using a combination of oil and air produced a bending strength of 430.08 N/mm² and a hardness of 305 HB. These improvements are based on average values, and no statistical significance testing was conducted. These findings suggest that the appropriate selection of quenching media can optimize the mechanical properties of SKD 61, which is crucial for industrial applications requiring a combination of high toughness and strength.

Keywords: bending test; brinell hardness; cooling media; double quenching; single quenching.

1. Introduction

SKD 61 is a chromium hot-work tool steel that is widely used in various industrial sectors, particularly in the manufacturing of plastic molds and cutting tools [1], [2]. Due to its high toughness, good thermal resistance, and wear resistance, this material is also commonly applied in the production of machining tools such as lathe tools, drills, and dies [3]. The performance of SKD 61 steel is significantly influenced by its mechanical properties, including hardness, strength, and toughness [4]. Above all, hardness and heat resistance are critical to ensure the durability and stability of molds during prolonged manufacturing cycles.

One of the main factors that affect the mechanical properties of SKD 61 is its hardenability. It is defined as the material's ability to undergo a phase transformation throughout its volume when subjected to rapid heating and cooling. Hardenability is governed by several factors, such as chemical composition, grain size, and the applied heat treatment processes. In this context, the heat treatment method plays a crucial role in tailoring the final mechanical properties of the material [4], [5].

Double quenching is one of the advanced heat treatment techniques involving two sequential quenching stages, aimed at improving hardness uniformity and mechanical strength. This technique is often proposed to enhance the performance of tool steels beyond what is achievable through conventional single quenching. Despite the potential benefits, there is limited research exploring the effect of double quenching on SKD 61, particularly regarding its impact on bending strength and Brinell hardness [6]–[8].

From a metallurgical standpoint, single quenching typically results in the formation of martensitic structures upon rapid cooling, which contributes to increased hardness. However, this process may leave portions of retained austenite, depending on the cooling rate and alloy composition. Double quenching, especially when using different media or temperatures, can refine the microstructure by reducing retained austenite. This process enhances the formation of uniform martensite and potentially improves both toughness and strength [9]–[12].

Understanding these microstructural transformations is essential in evaluating the mechanical performance of SKD 61 subjected to different quenching strategies.

Therefore, this study aims to explicitly investigate the influence of single quenching and double quenching techniques on the mechanical behavior of SKD 61, with specific emphasis on bending strength and Brinell hardness. The results are expected to contribute to the optimization of heat treatment processes for tool steels in demanding industrial applications.

2. Experimental Methods

This research was conducted to investigate the effect of single quenching and double quenching heat treatment techniques on the mechanical properties of SKD 61 tool steel. The experimental procedure consisted of three main stages: specimen preparation, heat treatment, and mechanical testing. All procedures followed relevant ASTM standards to ensure accuracy and reliability of the results.

A total of 12 specimens of SKD 61 were prepared and categorized into four treatment groups: untreated specimens (non-heat treatment), single quenching using oil and air, double quenching using oil followed by air, and double quenching using oil in both stages. Each group contained three specimens to ensure reproducibility and consistency of the experimental data.

The quenching media used in this study were mineral-based quenching oil (commercial grade with a flash point of approximately 200°C and viscosity of 30 cSt at 40°C) and ambient air at room temperature (approximately 27°C). Oil was chosen for its high cooling capacity and ability to induce martensitic transformation effectively, which enhances hardness. Air was selected as a slower cooling medium to observe its influence on mechanical properties when used individually or in combination with oil, simulating practical industrial cooling conditions.

The specimens were heated in an electric furnace to a temperature of 1000°C and held for 15 minutes. After heating, the quenching process was carried out using two techniques:

- a. In the single quenching technique, specimens were cooled once using either oil or air as the quenching medium.
- b. In the double quenching technique, specimens underwent two successive quenching processes using a combination of oil and air or two oil quenches.

Mechanical testing included the three-point bending test and the Brinell hardness test [13], [14].

- a. The three-point bending test was conducted according to ASTM E290, using a universal testing machine to measure bending strength. The force applied and deflection were recorded, and the bending strength was calculated using the standard equation.
- b. The Brinell hardness test was performed in accordance with ASTM E10, using a 10 mm steel ball indenter. The diameter of the indentation on the specimen surface was measured and the hardness value was calculated using the Brinell formula.

The data obtained from the mechanical tests were tabulated and analyzed to compare the bending strength and hardness values across all treatment groups. The results were interpreted to determine the influence of quenching techniques on the mechanical performance of SKD 61 tool steel.

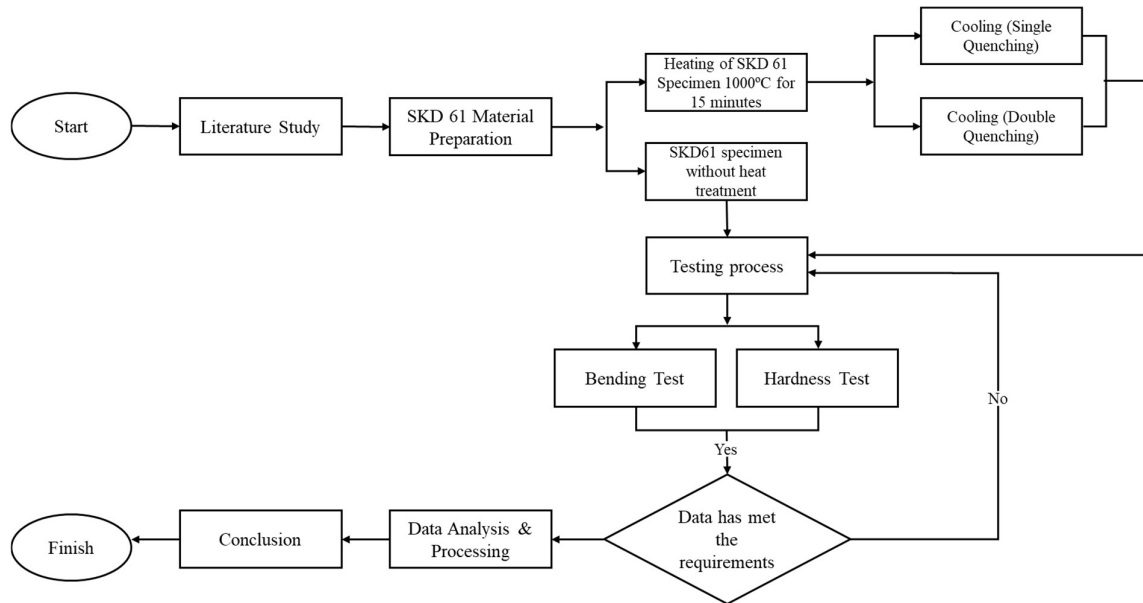


Figure 1. Research flow chart

2.1. Materials

SKD 61 were selected for this study due to their widespread industrial applications. The chemical compositions of the materials are shown in Table 1.

Table 1. Chemical composition of SKD 61 [4, 5]

Element (wt.%)									
C	Si	Mn	P	S	Ni	Cr	Mo	V	Cu
0.33-0.42	0.8-1.2	0.2-0.5	$0 \leq 0.03$	$0 \leq 0.03$	$0 \leq 0.25$	4.5-5.5	1.0-1.5	0.8-1.15	$0 \leq 0.25$

2.2. Sample Preparation

Experimental design is a description of the experimental process such as design drawings, design drawings or sample photos. Experimental design adjusts the problem formulation which describes the research or testing process to be carried out. When the problem formulation is more than one experimental design, it is then adjusted to the number of problem formulations sought. Lastly, each formulation is given a description of the working method or process.

The dimensions of each specimen in this test were based on applicable standards. In this study, the ASTM standard was used, which is an internationally recognized testing standard commonly applied as a reference in various testing procedures.

2.2.1 Bending Test Specimen

In the bending test, the standard used was ASTM E290-14, which is commonly applied to evaluate the ductility or the capacity of a material to undergo permanent deformation. The dimensions of the test specimen used in this study were 200 mm in length, 12.5 mm in height, and 12.5 mm in thickness. Figure 2 illustrates the technical drawing of the bending test specimen.

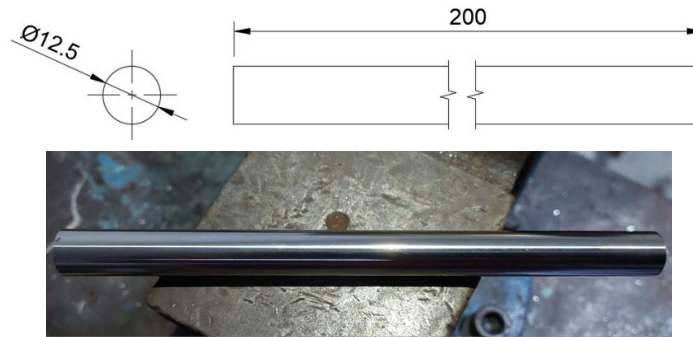


Figure 2. Bending test specimen

2.2.2 Brinell Hardness Test Specimen

In the Brinell hardness test, the standard used was ASTM E10. The specimen dimensions for the Brinell test were relatively small, with a length of 10 mm, a height of 10 mm, and a width of 10 mm. Figure 3 illustrates the technical drawing of the Brinell hardness test specimen.

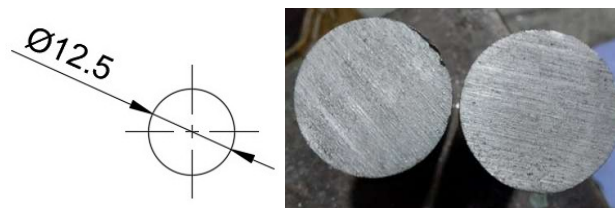


Figure 3. Brinell hardness test specimen

2.3. Heat Treatment

Each specimen was heated to 1000°C in a muffle furnace and held for 15 minutes to ensure uniform austenitization. The quenching process was then applied: single quenching: cooled in either oil or air and double quenching: two sequential quenching steps using either different (oil → air) or same (oil → oil) media. Figure 4 shows oil media for quenching process.



Figure 4. Oil media for quenching process

2.4. Mechanical Testing

2.4.1 Three-Point Bending Test

The three-point bending test is a testing method that involves two supports and one loading point, as shown in Figure 5. In this test, the specimen is subjected to a load applied at a single point, precisely at the center of the

beam (0.5 L). To ensure that the resulting moment reaches its maximum value, the load must be applied exactly at the 0.5 L position.

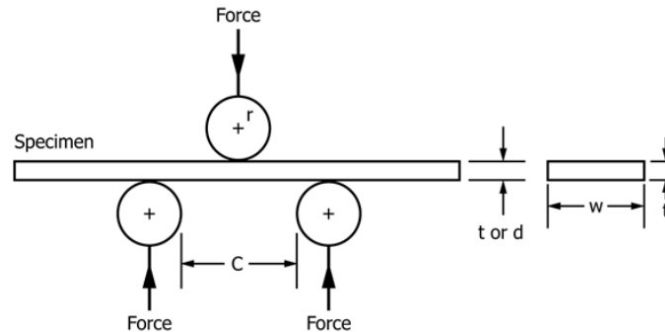


Figure 5. Three-point bending test scheme

The formula used to calculate the bending strength is presented in equation (1).

$$\sigma = \frac{3 \times P \times L}{2 \times W \times T^2} \quad (1)$$

where σ is the bending strength (N/mm^2), P is the applied load or force (N), L is the span length between the two supports (mm), W is the specimen width (mm) and T is the specimen thickness (mm). The dimensions of the test specimen are as follows: length = 200 mm, thickness = 12.5 mm, width = 12.5 mm, and span length between supports = 100 mm.

2.4.2 Brinell Hardness Test

The Brinell hardness test is conducted by statically pressing a hardened steel ball of a specified diameter onto the surface of a metal specimen. The surface of the specimen must be flat and clean before testing. After the applied force is removed and the steel ball is lifted from the indentation, the diameter of the resulting impression is measured to determine the hardness of the metal specimen. The standard diameter of the Brinell ball is $\varnothing 10$ mm, with a maximum permissible deviation of 0.005 mm.

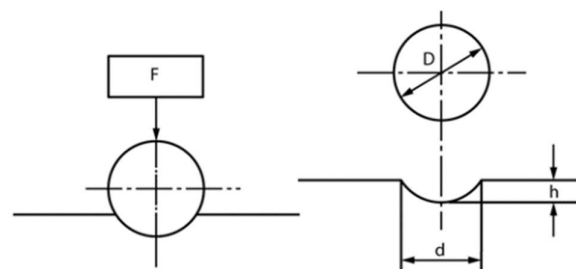


Figure 6. Brinell hardness test

The formula used to calculate the Brinell Hardness (BH) is presented in equation (2).

$$BHN = \frac{2F}{\pi D [D - \sqrt{D^2 - d^2}]} \quad (2)$$

where F is the applied load (kg or kgf), D is the diameter of the indenter (mm) and d is the diameter of the indentation (mm).

3. Results and Discussion

This section presents the bending strength and Brinell hardness test results of SKD 61 specimens subjected to single and double quenching using oil–air and oil–oil cooling media. The data are analyzed to evaluate the effects of each treatment method on the mechanical properties.

3.1. Bending Test Results

Figure 7 shows non-heat treatment specimen bending results. The non-heat-treated specimen was used as a baseline reference to compare the effects of heat treatment. Figure 8 (a) and (b) present bending results–single quenching using oil and air as quenching medium. Moreover, Figure 9 (a) and (b) present bending test results of double quenched specimens using oil–air and oil–oil as quenching media.



Figure 7. Non-heat treatment specimen bending results



Figure 8. Bending results–single quenching specimens using (a) Oil and (b) Air as quenching media



Figure 9. Bending test results of double quenched specimens (a) Oil–air and (b) Oil–oil as quenching media

The bending test result graph illustrates the comparison of bending strength among the four types of specimens. Specimens treated with quenching, both single and double, are presented in Figure 10.

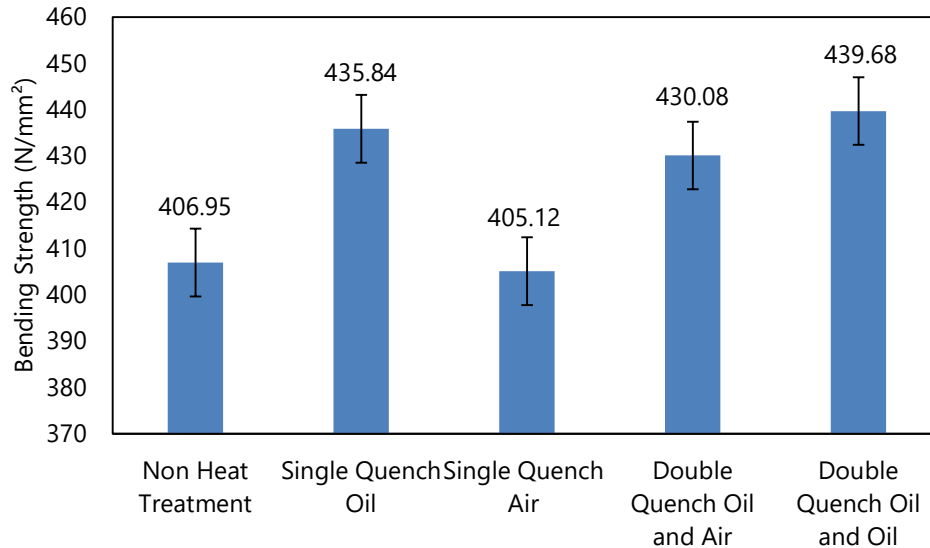


Figure 10. Comparison chart of bending test results

The non-heat-treated specimen was used as a baseline reference to compare the effects of heat treatment (see Figure 7). The bending test results showed an average strength of 406.89 N/mm², with individual specimen values of 406.89, 399.36, and 414.61 N/mm². These results represent the mechanical strength of SKD 61 material in its original condition without any heat treatment.

Specimens subjected to single quenching exhibited a notable increase in bending strength compared to the non-heat-treated specimens. The oil-quenched specimens achieved an average bending strength of 435.84 N/mm², with individual values of 435.84, 432, and 439.68 N/mm², indicating consistent enhancement due to the rapid cooling rate of oil, which promotes the formation of a hard martensitic structure. Air-quenched specimens also showed an improvement, with an average strength of 410.88 N/mm² and individual values of 410.88, 399.36, and 422.48 N/mm². Although air cooling improved strength compared to untreated specimens, it was less effective than oil due to its slower cooling rate. These results demonstrate that the choice of quenching medium plays a critical role in determining the mechanical performance of SKD 61 steel [5], [15], [16]

Specimens subjected to double quenching exhibited significant improvements in bending strength compared to single quenching. The combination of oil and air as quenching media resulted in an average bending strength of 430.08 N/mm², with individual values of 430.08, 424.32, and 435.84 N/mm² [17]. Meanwhile, specimens quenched twice using oil in both stages showed even higher strength, with an average of 439.68 N/mm² and individual values of 439.68, 435.84, and 443.52 N/mm². These results indicate that using oil for both quenching stages in the double quenching process provides superior mechanical performance for SKD 61 steel.

Figure 10 illustrates the comparison of bending strength among the four types of specimens. Specimens subjected to quenching, both single and double, demonstrated a significant increase in strength compared to the non-heat-treated specimens. Quenching with oil produced the best results followed by double quenching with oil and air, and finally single quenching with air. Although the difference in bending strength between specimens subjected to double quenching with oil–air and those with oil–oil was relatively small, the results indicate that quenching with oil enhances the ductility of SKD 61 material. Moreover, the quenching process effectively increases the hardness of SKD 61. Figure 10 clearly confirms that the quenching process significantly improves the mechanical strength of SKD 61 steel.

3.2. Brinell Test Results

Figure 11 shows non-heat treatment specimens for Brinell hardness test. Figure 12 (a) and (b) shows single quenching specimens using oil and air as cooling media specimens for Brinell hardness test. Figure 13 (a) and (b) shows double quenching specimens using oil–air and oil–oil as cooling media specimens for Brinell hardness test.



Figure 11. Non-heat treatment specimen specimens for Brinell hardness test

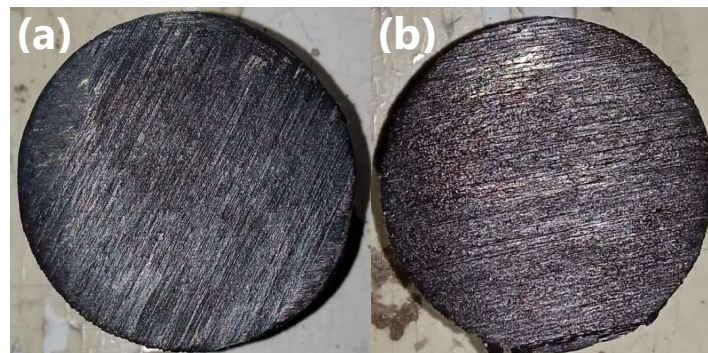


Figure 12. Single quenching specimens using (a) Oil and (b) Air as cooling media for Brinell hardness test

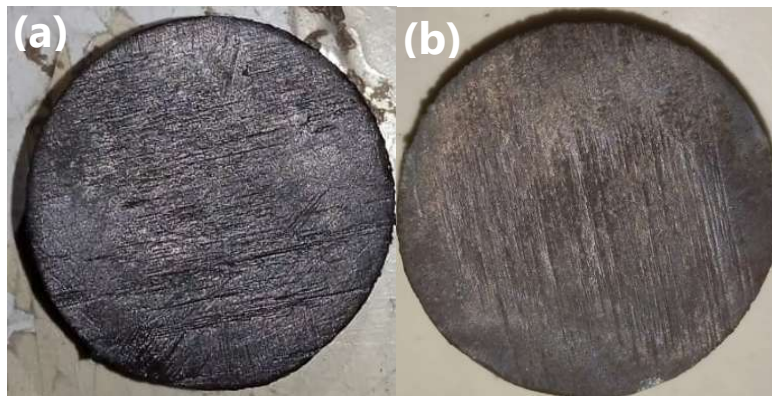


Figure 13. Double quenching specimens using (a) Oil–air and (b) Oil–oil as cooling media for Brinell hardness test

Figure 14 presenting the results of the Brinell hardness tests value, comparing each test specimen based on the different quenching media and methods applied.

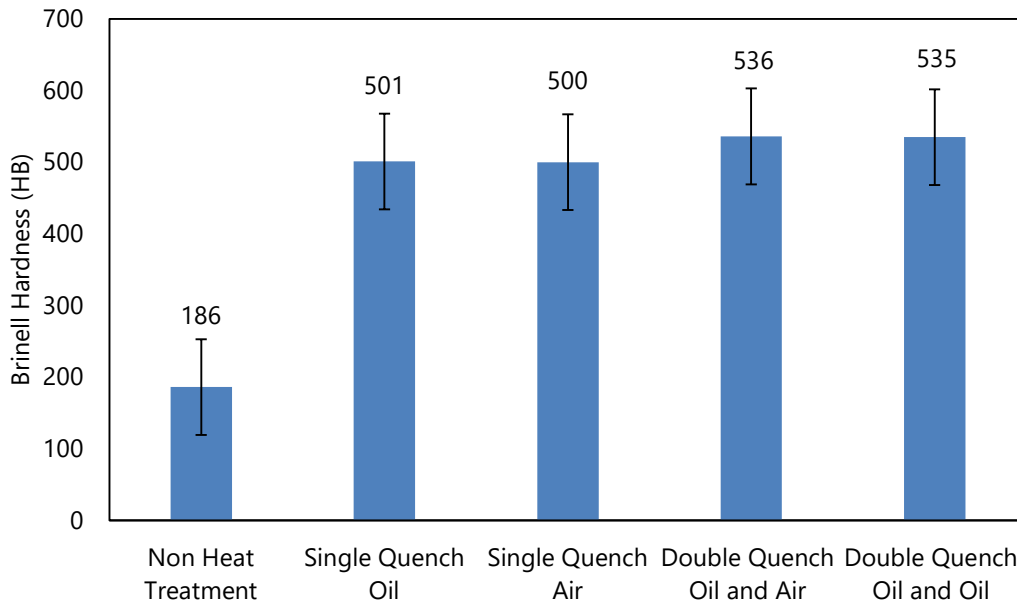


Figure 14. Comparison chart of Brinell hardness test value results

Figure 14 shows the hardness of SKD 61 material before undergoing the heat treatment process ranged between 170 and 210 HB. This initial hardness reflects the original condition of the hot-work tool steel, which has not yet experienced microstructural changes due to heating and rapid cooling. The test results showed variations in hardness values, with the highest recorded at 210 HB and the lowest at 170 HB. This data provides an important baseline for understanding the changes in hardness of SKD 61 material after heat treatment, allowing for a meaningful comparison between pre- and post-treatment values.

The hardness test results showed that quenching using oil as the cooling medium produced hardness values of 555, 500, and 450 HB, indicating a significant improvement in the hardness of SKD 61 material [18]. The highest value, 555 HB, suggests that oil provides rapid and uniform cooling, promoting the formation of a hard martensitic structure [19]. In comparison, air quenching yielded hardness values of 530, 500, and 470 HB. Although slightly lower than those achieved with oil, air was still effective in increasing hardness. The lower values reflect the slower cooling rate of air, which leads to reduced martensite formation compared to oil quenching.

The Brinell hardness test results for specimens treated with double quenching using oil and air were 525, 530, and 555 HB, while those treated with oil in both stages recorded 530, 522, and 555 HB. Both methods yielded consistently high hardness values, indicating that the combination of cooling media in the double quenching process has a synergistic effect in enhancing the hardness of SKD 61 material. The stepwise cooling process, starting with oil followed by air, contributes to the formation of a harder and more stable martensitic structure. Although minor differences in hardness values were observed, the results show that both quenching approaches are comparably effective in improving material hardness.

The Brinell hardness test in Figure 14 illustrates the comparison of hardness values among the four types of specimens. Specimens that underwent quenching—both single and double—showed a significant increase in hardness compared to the non-heat-treated specimens. Quenching with oil produced the highest hardness values, followed by double quenching with oil and air, and finally single quenching with air. Although the difference in hardness between specimens treated with oil–air and those with oil–oil in double quenching was relatively small. The data clearly indicate that oil as a quenching medium provides optimal hardening effects for SKD 61 material. Overall, Figure 14 confirms that the quenching process effectively enhances the hardness characteristics of SKD 61 steel.

4. Conclusion

Based on the results of the bending and Brinell hardness tests conducted on both heat-treated and non-heat-treated SKD 61 specimens, it can be concluded that heat treatment significantly enhances the mechanical properties of the material. The average bending strength of the untreated specimen was 406.89 MPa, which increased to 435.84 MPa after single quenching with oil, and 410.88 MPa with air. Double quenching using oil and air resulted in 430.08 MPa, while using oil in both stages produced the highest strength of 439.68 MPa, indicating that oil is more effective than air in improving bending strength.

Similarly, Brinell hardness improved from an average of 186 HB in the untreated condition to 501 HB and 500 HB with single quenching using oil and air, respectively. Double quenching with oil and air achieved 536 HB, while oil-oil produced 535 HB, confirming that all quenching methods significantly improve hardness, with oil-air double quenching yielding the highest result.

These findings suggest that the double quenching technique, particularly with oil-air media, can be considered a viable heat treatment method for improving the wear resistance and strength of SKD 61 in industrial applications such as hot-work tooling, extrusion dies, and plastic molding.

For future work, it is recommended to investigate the effect of post-quenching tempering on the balance between hardness and toughness. For better understanding of the phase transformations involved, microstructural analysis is also suggested to conduct (e.g., SEM, XRD). In addition, a broader range of quenching media and controlled cooling rates could be explored to optimize the treatment process for different application needs.

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