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Experimental study on annealing S45C steel: effect of temperature and time on hardness, impact strength

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ABSTRACT

Steel generally exhibits poor wear and friction resistance, making it necessary to improve its surface mechanical properties, particularly hardness and microstructure, to enhance performance. Heat treatment is one of the most effective methods for achieving these improvements. This study aimed to optimize the heat treatment parameters of S45C medium-carbon steel to improve hardness and impact strength using response surface methodology (RSM). Experimental trials were conducted at annealing temperatures of 800 °C, 850 °C, and 900 °C with holding times of 30, 60, and 90 minutes, followed by cooling in water, oil, or air. Hardness (HRC) and impact strength (Nm/mm²) were measured, and the data were analyzed using RSM with a central composite design (CCD). Quadratic models were found to be statistically significant for both hardness (Prob > F = 0.0222) and impact strength (Prob > F = 0.0338), confirming their validity. The optimization results indicated that a holding time of 60 minutes within the 850-900 °C range provides the best balance between high hardness (>55 HRC) and adequate impact strength (>0.68 Nm/mm²). These findings not only validate the predictive capability of RSM in heat treatment optimization but also provide practical guidelines for industrial applications of S45C steel in automotive, tooling, and structural components.

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1. INTRODUCTION

In today's industrial landscape, the development of new products often involves the use of novel materials and advanced production processes [1]. The selection of materials plays a crucial role in determining product competitiveness and fostering innovation, particularly when supported by cutting-edge technology [2]. However, before materials are implemented in industrial applications, it is essential to understand their characteristics in detail and ensure they can be processed efficiently using modern manufacturing techniques [3]. As such, all materials intended for industrial use must undergo rigorous testing to evaluate their performance and suitability [4].

Mechanical properties such as hardness, ductility, strength, toughness, stiffness, and fatigue resistance are vital indicators of a material's quality and functionality [5]. Each of these properties may require different testing methods to obtain accurate evaluations [6]. Among the most commonly conducted tests is the hardness test, which assesses a material's resistance to plastic deformation. Hardness can be measured either manually using scratch techniques or more accurately through a hardness testing machine [7]. The data obtained from this test are crucial in assessing material quality for various industrial applications, especially those involving pure metals and alloys exposed to pressure, loads, or extreme temperatures [8]–[10].

In addition to hardness, impact testing is another important method used to determine a material's strength, toughness, and ductility. This test evaluates a material’s ability to absorb energy during sudden loading, simulating real-world conditions such as those encountered in transportation or construction industries [11]–[13]. Unlike tensile or hardness tests, which are conducted under static or slowly applied loads, impact tests involve dynamic loading, where materials are subjected to sudden forces [14]. The test reflects a material’s resistance to brittle fracture, considering factors such as impactor speed, notch presence, plate thickness, and mass [15]. The toughness of a material, or its ability to resist shock loads, is essential for ensuring durability under unpredictable service conditions [16].

In mechanical testing, the type of load applied is a distinguishing factor. Static loading is used in tensile, compression, and torsion tests, while dynamic loading is employed in impact testing [17]. During dynamic loading, the kinetic energy from an impact is absorbed and transformed by the material through mechanisms such as plastic deformation, friction, and inertia [18]. This energy absorption capacity is critical, especially for metallic materials, which are predominantly used in industrial applications. Although tensile strength is typically standardized, impact energy must be tested to ensure that a material not only performs well under static conditions but also withstands sudden loads [19], [20]. A material possessing both high tensile and impact energy exhibits superior toughness and is more desirable for manufacturing purposes [21].

High-quality materials are essential for manufacturers striving to maintain product reliability and reputation in the market [22]. Therefore, understanding the influence of factors such as temperature, dynamic load, and friction on material properties is crucial. Selecting the right material and applying appropriate treatments, such as heat treatment, can significantly enhance mechanical performance, particularly impact energy [23]. This study aims to analyze and optimize the heat treatment process parameters affecting the hardness and impact energy of S45C medium carbon steel using the response surface methodology (RSM) approach. This paper consists of: section 2 is the basic theory, which is divided into two parts: first is the heat treatment and testing properties, and second is the RSM. Section 3 presents the experimental method, which is divided into two parts: first is the experimental design, and the second are tools and materials. In section 4 are result and discussion. Last section 5 is the conclusion.

2. BASIC THEORY

2.1. Heat treatment and testing properties

Hardness testing is a commonly used method to determine the hardness of a material, which refers to its resistance to deformation under applied pressure. This resistance is measured by applying a specific force through an indenter of a certain shape onto the material's surface. Several methods are available for measuring hardness, including Brinell hardness (HB), which can be seen in Figure 1, Vickers hardness (HV), Rockwell hardness using a ball indenter (HRB), and Rockwell hardness using a conical indenter (HRC) [24]–[26]. Among these, the HB method is one of the most widely used techniques for testing the hardness of metallic materials [6]. HB is determined by the ratio between the applied force (F) and the surface area of the indentation (A). It can be formulated by (1).

$$HB = \frac{F}{A} kgf/mm2 = \frac{9.8\,F}{A} N/mm2 \tag{1}$$

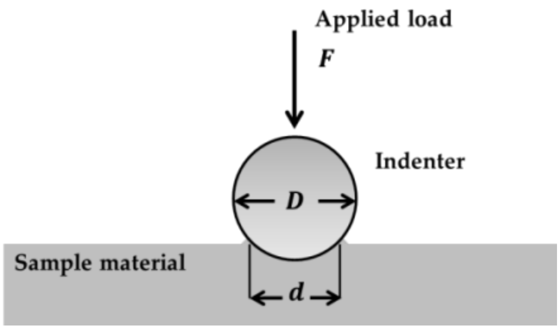

Figure 1. The principle of HB test

Impact testing is a method used to evaluate a material's behavior under rapid or sudden loading. During this test, a significant energy absorption process occurs when the load strikes the specimen. The amount of energy absorbed by the material can be calculated using the principle of potential energy difference. This absorbed energy is then dissipated through various material responses, such as plastic deformation, hysteresis effects, and inertial effects. Schematic impact testing can be seen in Figure 2.

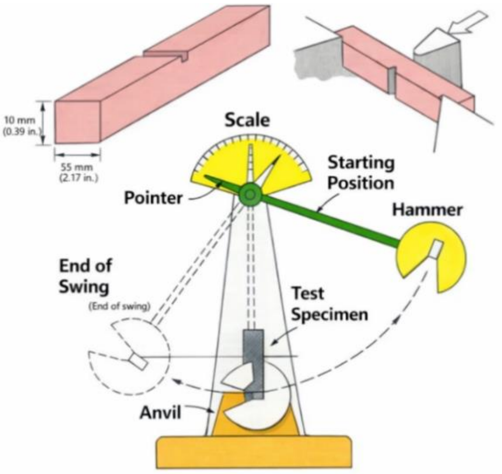

Figure 2. Schematic of using the Charpy impact testing (ASTM D6110–04)

The basic principle of the impact test involves calculating the energy supplied by the impactor (usually in the form of a pendulum) and the energy absorbed by the specimen. When the pendulum is raised to a certain height, it possesses maximum potential energy. As it swings downward and strikes the specimen, this potential energy is converted into kinetic energy, which reaches its maximum just before impact. A portion of this kinetic energy is absorbed by the specimen, causing deformation and ultimately fracture.

In this test, the amount of energy absorbed by the material until fracture occurs is used as a measure of its impact resistance (HI). The impact resistance of the material, as determined using the Charpy method, can be calculated based on the equation provided in ASTM D6110–04. Standard test method for determining the Charpy impact resistance of notched specimens of plastics as in (2) [27].

$$HI = \frac{E}{A} = \frac{m \, .g \, (h_1 - h_2)}{A} N/mm2 \quad (2)$$

Where HI is the impact energy (J/mm²) m, is the mass of the pendulum hammer (kg), g is the acceleration due to gravity (9.81 m/s²), h_1 is the height of the center of the pendulum before impact (m), and h_2 is the height of the center of the pendulum after impact (m).

2.2. Response surface methodology

In this research, the process of forming tractor wheel fins is carried out using metal forming tools, specifically a punch and die. To determine the required force, the fin of the tractor wheel is formed through a single embossing process. This force corresponds to the amount needed to bend the ends of the tractor wheel fins [28].

Mathematically, RSM models the relationship between multiple explanatory variables and one or more response variables. Originally proposed by Box and Wilson in 1951 and based on the design of experiments (DoE) framework developed earlier by Fisher, RSM aims to identify the optimal value of the response variable corresponding to specific levels of the explanatory variables. In practical applications, experimental data often contain errors, making statistical interpretation an essential part of RSM analysis. Fundamentally, RSM employs linear regression models to capture the relationship between explanatory and response variables. The methodology typically involves two main stages, with the first stage—known as first-order regression modeling—represented by a linear polynomial equation. An example of a first-order RSM equation with two factors is presented (3).

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \varepsilon \quad (3)$$

In this context, x_i represents the factor studied in the experiment, also referred to as the explanatory variable, while y denotes the response variable. The experimental design used in (1) follows a factorial structure similar to that in the DoE, but with the addition of a center point between the levels of each factor. This inclusion allows for a more accurate estimation of curvature in the response surface. An example of the experimental design used in conjunction with (1) is taken from [29]. This design aims to identify the optimal response value within the range of factor levels investigated. However, the (1) may still exhibit a lack-of-fit, as discussed in [30].

The next step involves increasing the degree of the polynomial equation to a second-order model. This enhancement allows for better modeling of curvature in the response surface. An example of a second-order polynomial equation with two factors is shown (4).

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_{11} X^2 + \beta_{11} X^2 + \beta_{12} X_{12} X_{12} + \varepsilon \quad (4)$$

The optimal response point can be determined by taking the partial derivatives of (2) with respect to each explanatory variable [31]. This process yields the factor level settings that optimize the response variable and is referred to as mathematical optimization. The practical advantages of RSM are not always immediately apparent in first-order or second-order models. According to Wang *et al.* [32], if (1) shows no lack-of-fit, it indicates that the optimal point does not lie within the first-order design space. Therefore, the factor levels must be adjusted or "shifted" in the direction that improves the response. This ability to shift and explore factor levels toward optimal conditions is one of the key strengths of RSM. It enables the identification of optimal response points even beyond the initial first-order experimental region. The (2) is then applied in a refined experimental area, typically using advanced designs such as the central composite design (CCD) or Box-Behnken design (BBD) [33].

3. EXPERIMENTAL METHOD

3.1. Experimental design

The method used in this study is a quantitative approach involving the calculation of hardness and strength levels of several medium carbon steel specimens after undergoing heat treatment. To enhance the hardness of the steel, a hardening process is performed, in which the specimens are heated in a furnace at various annealing temperatures, specifically 800 °C, 850 °C, and 900 °C. Once the target temperature is reached, the specimens are cooled using different cooling media: water, oil, and air. Subsequently, the RSM is applied to process the data and analyze the resulting hardness and strength responses of the steel. Several methods are employed to measure the hardness of the heat-treated medium carbon steel, including the Brinell and Rockwell hardness tests, while the Charpy impact test is used to evaluate the material's strength.

3.2. Tools and materials

Figure 3 shows the hardness testing was conducted using the Brinell method to determine the hardness values at several bending areas of the specimen. The test was performed with an AFFRI 206 MX hardness testing machine, as shown in Figure 3(a) [34]. The heat treatment process was carried out using a shop hardening furnace with a maximum operating temperature of 1,200 °C, as illustrated in Figure 3(b). The material preparation process is carried out to ensure the accuracy and consistency of the test specimens. Specifically, it is intended to confirm that the material used in this study is S45C medium carbon steel.

(a) (b)

Figure 3. HB testing equipment with (a) AFFRI 206 MX machine and (b) shop hardening furnace (max. 1,200 °C)

3.3. Testing procedure
3.3.1. Hardness testing
Hardness measurements were performed using both the Brinell and Rockwell methods to ensure accuracy and cross-validation.

- HB test: conducted in accordance with ASTM E10. A steel ball indenter with a 10 mm diameter was applied under a load of 3000 kgf for 10–15 seconds. Indentations were made at multiple regions of each specimen to obtain an average value and reduce local variation effects.
- HRC test: conducted in accordance with ASTM E18 using a diamond cone (Brale) indenter and a test load of 150 kgf. Measurements were repeated three times per specimen, and the average values were reported.

3.3.2. Impact testing
Impact strength was evaluated using the Charpy V-notch method in accordance with ASTM E23. Specimens were prepared with a standardized V-notch (2 mm depth, 45° angle). Each specimen was subjected to a pendulum impact load, and the absorbed energy was recorded. To standardize results, impact strength values were expressed in Nm/mm², calculated by dividing the absorbed energy by the cross-sectional area at the notch.

3.3.3. Data analysis
The experimental results for hardness and impact strength were analyzed using RSM with a CCD. Statistical analysis, including analysis of variance (ANOVA), was performed to evaluate the significance of each factor (temperature, holding time, and cooling medium) and their interactions. Quadratic models were selected as the best fit to predict responses, and optimization was conducted using desirability functions to identify parameter combinations that provided the best balance between hardness and impact strength.

4. RESULT AND DISCUSSION
In this section, the research results are presented along with a discussion of each response obtained. To optimize the heat treatment parameters, a predictive model was developed to evaluate the effect of these parameters on the material's response. The model was based on the experimental data obtained from the heat treatment process, as summarized in Table 1.

The experimental data of heat treatment parameters for S45C steel are summarized in Table 1. The results reveal distinct variations in hardness and impact energy depending on both temperature and holding time. In general, holding times up to 60 minutes within the 850-900 °C range produced the highest hardness values (exceeding 55 HRC), while optimal impact energy was observed at holding times of 60-75 minutes.

Table 2 presents the model fit values for the hardness data. Based on the analysis, a quadratic model was selected as it provides more statistically significant results. This is supported by the probability value of 0.0222, which is less than the significance level of 0.05.

Table 1. Heat treatment test results data

No	Temp. (°C)	Holding time (minutes)	Hardness (HRC)	Impact energy (Nm/mm^2)
1	800	30	47.3	0.454
2	800	60	58.6	0.698
3	800	90	38.5	0.566
4	850	30	42.3	0.454
5	850	60	57.7	0.671
6	850	90	50.7	0.618
7	900	30	36.2	0.466
8	900	60	54.4	0.752
9	900	90	57.2	0.631

Table 2. Model sequential untuk springback

Source	Sum of squares	DF	Mean squares	F value	Prob > F	
Mean	21,795.6	1	21,795.6			
Linear	72.65	2	36.33	0.42	0.6735	
2FI	222.01	1	222.01	3.78	0.1096	
Quadratic	**270.74**	**2**	**135.37**	**17.5**	**0.0222**	**Suggested**
Cubic	23.10	2	11.55	103.94	0.0692	Aliased
Residual	0.11	1	0.11			
Total	22,384.2	9	2487.1			

The ANOVA table for the hardness model is presented in Table 3. It shows a "Prob > F" value of 0.0222. Since this value is less than the significance level of 0.05, it is considered statistically valid.

Table 3. ANOVA for hardness after backward process (<0.05)

Source	Sum of squares	DF	Mean squares	F value	Prob > F	
Model	560.70	4	140.17	20.09	0.0065	significant
A	1.93	*1*	1.93	0.28	0.6270	
B	70.73	*1*	70.73	10.14	0.0334	
B^2	266.04	*1*	266.04	38.13	0.0035	
AB	222.01	*1*	222.01	31.82	0.0049	
Residual	27.91	4	6.98	20.09	0.0065	
Cor total	588.61	8				

Design expert generated the (5) to determine the desired hardness.

$$Hardness = +247.56667 - (0.28667 * Temperatur) - (2.56944 * Holding\ Time) - (0.012815 * Holding\ Time2) + (4.96667E - 003 * Temperature * Holding\ Time) \quad (5)$$

The 2D graph for hardness, shown in Figure 4, presents the contour plot of (5). The figure indicates that the material's hardness can be increased at holding times greater than 60 minutes within the given temperature range. Table 4 presents the suitability values for the impact energy data. Based on these results, it was selected because it demonstrated higher significance compared to the other models tested. This selection is further supported by the probability value of 0.0213, which is less than 0.05, indicating statistical significance.

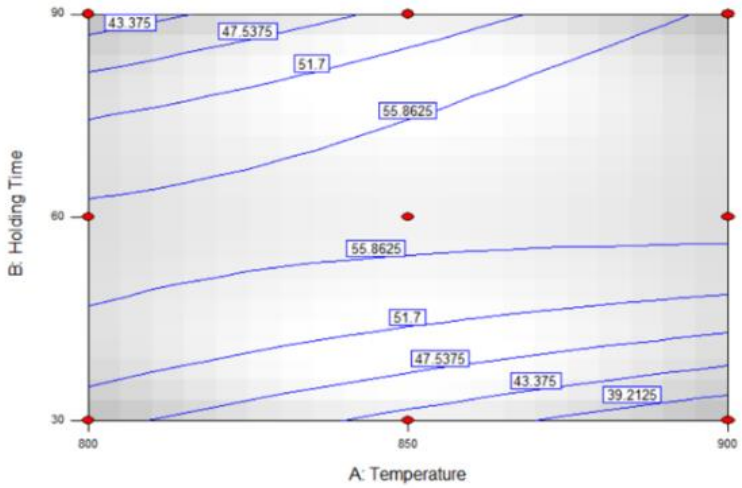

Figure 4. Variation of hardness with holding time and temperature (contour plot)

Table 4. Sequential model analysis for impact energy data

Source	Sum of squares	DF	Mean squares	F value	Prob > F	
Mean	3.07	1	3.07			
Linear	0.035	2	0.018	1.81	0.2429	
2FI	7.023E-04	1	7.023E-04	0.061	0.8151	
Quadratic	**0.052**	**2**	**0.026**	**12.84**	**0.0338**	**Suggested**
Cubic	2.968E-04	2	1.484E-04	0.026	0.9571	Aliased
Residual	5.751E-03	1	5.751E-03			
Total	3.16	9	0.35			

The ANOVA table for the bending load model is presented in Table 5. The table shows a "Prob > F" value of 0.0338, which is lower than the significance threshold of 0.05. This result indicates that it is statistically significant and can be considered valid for describing the bending load data.

Table 5. ANOVA for impact energy after backward process (<0.05)

Source	Sum of squares	DF	Mean squares	F value	Prob > F	
Model	0.082	2	0.041	21.36	0.0019	significant
B		*1*	0.032	16.83	0.0063	
B^2		*1*	0.050	25.88	0.0023	
Residual	0.012	6	1.925E-003			
Cor total	0.094	8				

Statistical analysis using RSM (Tables 2-5) confirmed that it provided the best fit for both responses, with Prob > F values under 0.05. The predictive equations generated enable accurate estimation of mechanical properties for conditions beyond the experimental matrix. Design expert also generated the (6) to determine the desired parameters and the target impact energy.

$$Impact\ Strength = -0.089000 + (0.023494 * Holding\ Time) - 1.75370E - (004 * Holding\ time^2) \quad (6)$$

The 2D graph for impact energy, shown in Figure 5, presents the contour plot of (6). The figure indicates that the impact energy can be increased when the holding time is within the range of 60-75 minutes. This increase occurs without being influenced by the heating temperature. Parameter optimization was performed using Design-Expert V.6 software to determine the optimal combination of several parameters. The objective was to identify the parameter and response combinations that yield the best possible solution. The desired optimal solution (desirability) was defined as achieving both high hardness and high impact energy, as illustrated in Figure 6. Figure 7 presents the optimization contour graph for each response. The grey shading in the overlay plot represents the boundaries for all the desired responses. In this case, the optimal process control region is defined where the hardness exceeds 55 HRC, and the impact energy is not less than 0.68 Nm/mm².

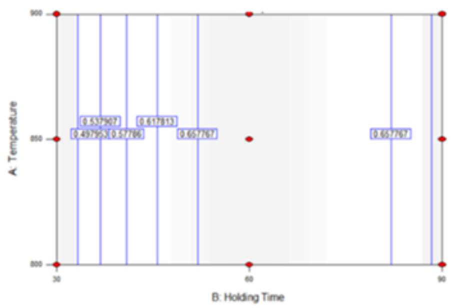

Figure 5. Variation of impact energy with holding time and temperature (contour plot)

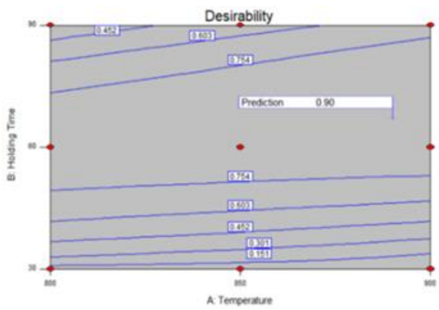

Figure 6. Desirability plot for optimal combination of hardness and impact energy

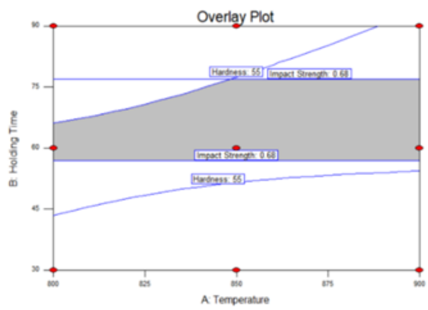

Figure 7. Overlay plot showing the optimal heat treatment region

Optimization using the desirability method (Figure 7) identified a process window where hardness exceeded 55 HRC while maintaining impact energy above 0.68 Nm/mm². Validation tests under these optimized parameters (Table 6) confirmed the critical influence of cooling media: water quenching yielded the highest hardness but the lowest toughness, while oil and air cooling offered a more balanced combination of properties. The optimized heat treatment parameters obtained from the previous analysis were further tested using three types of cooling media: water, air, and oil. Each cooling medium was applied to evaluate its effect on the mechanical properties of the material. The specific heat treatment parameters and the corresponding test results are summarized in Table 6.

Table 6. Data on the results of optimizing heat treatment testing

No	Temp. (°C)	Holding time (minutes)	Cooling media	Hardness (HRC)	Impact energy (Nm/mm2)
1	900	60	Water	58.8	0.698
2	900	60	Air	57.3	0.642
3	900	60	Oil	56.2	0.616

The results clearly demonstrate that both heating parameters and cooling media exert a significant influence on the hardness and impact energy of S45C medium carbon steel. Statistical analysis using RSM confirmed that quadratic models were the most suitable for both responses, as indicated by ANOVA values with Prob > F well under 0.05, which verifies the strong relationship between the tested factors and output responses. For hardness, the interaction between heating temperature and holding time was particularly dominant, where maximum hardness was achieved at holding times greater than 60 minutes, especially within the thermal range of 850-900 °C, due to more complete austenitization that produced finer martensitic transformation during rapid cooling. Similar findings were reported by [35], who stated that extended soaking time at elevated temperatures enhanced martensitic refinement in medium-carbon steels, increasing hardness without inducing major grain coarsening. Likewise, [36] confirmed that holding durations beyond 60 minutes at 850-900 °C resulted in optimal hardness levels in automotive-grade steels due to stable martensite formation. The effect of cooling rate was also very dominant: water quenching consistently produced the highest hardness because of extreme quench severity, whereas oil and air cooling resulted in lower hardness since slower cooling rates allowed the formation of softer transformation products such as bainite and pearlite. These results reinforce the typical hardness–toughness trade-off behavior in heat-treated steels; however, this study advances current understanding by developing a statistically validated predictive model and verifying it experimentally under the optimal parameter combination (900 °C, 60 minutes), where model prediction showed strong correlation with actual measured values.

The impact energy results clearly showed the expected hardness–toughness trade-off in steel heat treatment, where specimens quenched in oil or air achieved higher impact energy compared to water quenched samples due to lower residual stresses and a more balanced microstructure that preserved ductility, while water quenching produced the highest hardness but the lowest impact energy because of the predominantly martensitic structure which is prone to brittle fracture. This trend was consistent at all tested temperatures, proving that the quenching medium had a stronger influence on fracture behavior than temperature variation in this study. The contour plots also indicated that the optimal impact energy region occurred at holding times between 60 and 75 minutes, regardless of heating temperature, meaning that holding time had a stronger role in toughness control compared to heating temperature within this range. Design expert optimization successfully identified a safe process window where hardness remained above 55 HRC while impact energy stayed above 0.68 Nm/mm². Validation experiments at the predicted optimum (900 °C, 60 minutes) confirmed the model accuracy, showing that water quenching produced maximum hardness but minimum toughness, while oil and air cooling produced a much more desirable balance of mechanical properties for more practical engineering applications.

The optimization of annealing and quenching parameters for S45C medium-carbon steel carries broader significance beyond hardness and impact energy responses. In industrial applications, secondary properties such as fatigue resistance, machinability, and weldability are equally essential to ensure reliable long-term service behavior. The improved impact energy obtained within the optimized holding time range of 60-75 minutes, combined with slower quenching media (oil or air), implies a corresponding positive influence on fatigue performance, since enhanced ductility together with lower residual stresses directly reduces crack initiation and retards crack propagation during cyclic loading. This is particularly important for automotive shafts, gear elements, and axle components, which routinely operate under fluctuating stress states and variable load amplitude. Conversely, water-quenched specimens, although superior in hardness, experience inferior fatigue life potential due to increased brittleness and stress amplification at microstructural stress concentrators. From a manufacturing perspective, excessive hardness is undesirable for machining because it increases cutting forces, shortens tool life, and elevates cost. The findings demonstrate that oil and air-cooling yield hardness levels around 56-57 HRC while still maintaining adequate toughness, thereby facilitating easier drilling, milling, and shaping without sacrificing in-service durability. Weldability is similarly linked to microstructure and hardness distribution. Extremely hard martensitic structures formed during water quenching increase cracking risk within the HAZ during welding, while mixed martensitic–bainitic structures generated through oil or air quenching reduce stress gradients and promote safer joining. Thus, the optimized process window provides a rational compromise between durability, manufacturability, weld integrity, and material economy. Collectively, these extended implications emphasize that the optimized annealing strategy is industrially relevant because it simultaneously balances hardness, toughness, fatigue resistance, machinability, and weldability to suit diverse engineering requirements.

Overall, this study demonstrates that both heat treatment parameters and cooling media selection strongly influence the mechanical behavior of S45C steel. This connection is established by linking statistical modeling with metallurgical mechanisms. Consequently, the findings provide practical guidelines for tailoring heat treatment processes in industrial applications.

5. CONCLUSION

Based on the experimental results and statistical analysis, it can be concluded that the optimization of heat treatment parameters for S45C medium carbon steel using RSM with a CCD successfully produced statistically significant quadratic models for both hardness and impact energy. The ANOVA results yielded Prob > F values of 0.0222 for hardness and 0.0338 for impact energy, both below the significance threshold of 0.05, confirming the validity of the models. The study revealed that hardness increases with longer holding times, particularly above 60 minutes, and is strongly influenced by cooling rate, with water quenching providing the highest hardness due to rapid martensitic transformation. In contrast, impact energy exhibited an inverse relationship with hardness, with oil and air cooling delivering superior toughness by promoting a more balanced microstructure and reducing brittle fracture susceptibility. The optimization process identified a parameter range—holding time between 60 and 75 minutes and temperatures of 850-900 °C—that provides an optimal balance between hardness (>55 HRC) and impact energy (>0.68 Nm/mm^2). From an application perspective, achieving the best overall performance requires tailoring the heat treatment parameters to the intended service conditions. For applications prioritizing maximum hardness, water quenching at 900 °C for 60 minutes is recommended, whereas for applications requiring a balance of strength and toughness, oil or air cooling at similar holding times is preferable. Beyond these practical guidelines, the findings highlight the potential of statistical modeling to reduce experimental iterations and support energy-efficient heat treatment practices. By enabling accurate prediction of material response, the approach also contributes to predictive maintenance strategies in manufacturing, ensuring reliable performance while lowering costs and energy use. Thus, this study not only advances the understanding of S45C heat treatment behavior but also reinforces its relevance to modern sustainable manufacturing and industrial applications.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available within the article.

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