

# Experimental Analysis of Annealing Conditions on Hardness Characteristics of SS400 Steel Cane Cutter Blades

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## Abstract

In the sugarcane processing industry, problems often arise during the milling season, one of which is the cane cutter machine, which functions as a sugarcane shredder consisting of various blades mounted on a holder made of SS400 steel. These blades play a crucial role in the sugarcane cutting process before milling, and their performance is greatly influenced by the mechanical properties of the material used. SS400 steel, which is a low-carbon steel, has relatively low hardness and high ductility. However, damage to the cane cutter blades often occurs. This study aims to analyze the effect of temperature and holding time variations in the annealing process on the hardness value of SS 400 steel used as a cane cutter blade. The annealing process is one of the important processes in improving the mechanical properties of a material such as its hardness and ductility. In this study, the cane cutter blade made of SS400 steel was given annealing heat treatment with different temperatures and holding times. Based on the results of the annealing heat treatment on SS400 steel with temperature variations of 750°C, 775°C, and 800°C, each combined with holding times of 30, 45, and 60 minutes, it was found that for every temperature variation, the longest holding time resulted in the lowest hardness value. The lowest average hardness, 34.24 HRA, was obtained at 800°C with a holding time of 60 minutes. Conversely, the highest average hardness, 39.77 HRA, was achieved at 775°C with a holding time of 30 minutes.

**Keywords:** SS400 Steel, Hardness, Heat Treatment, Sugarcane

## 1. INTRODUCTION

The cane cutter blade is a crucial component in the production process of the sugarcane industry, particularly in the cutting stage before the milling process. The performance of the cane cutter blade is highly influenced by the mechanical properties of the material used. SS400 steel, classified as low-carbon steel with a carbon content of less than 0.3%, exhibits relatively low hardness, softness, and high ductility, making it suitable for applications where flexibility and resistance to deformation are prioritized over high tensile strength [1]. The performance of the cane cutter machine becomes highly demanding during the milling season, often leading to damage to the blade holders and necessitating frequent maintenance and replacements [2]. This situation underscores the need for enhancing the mechanical properties of SS400 steel to improve the operational lifespan of cane cutter blades.

To enhance the performance and durability of these blades while minimizing maintenance costs, an appropriate heat treatment process is critical to improving their toughness. Heat treatment is known to significantly influence the mechanical characteristics of metallic materials such as steels [3][4]. Various heat treatment methods can mitigate undesirable material characteristics by tailoring properties like hardness, ductility, and relieving residual stresses induced during manufacturing [5][6]. This complexity in heat treatment technologies allows engineers to optimize material performance for specific applications [7].

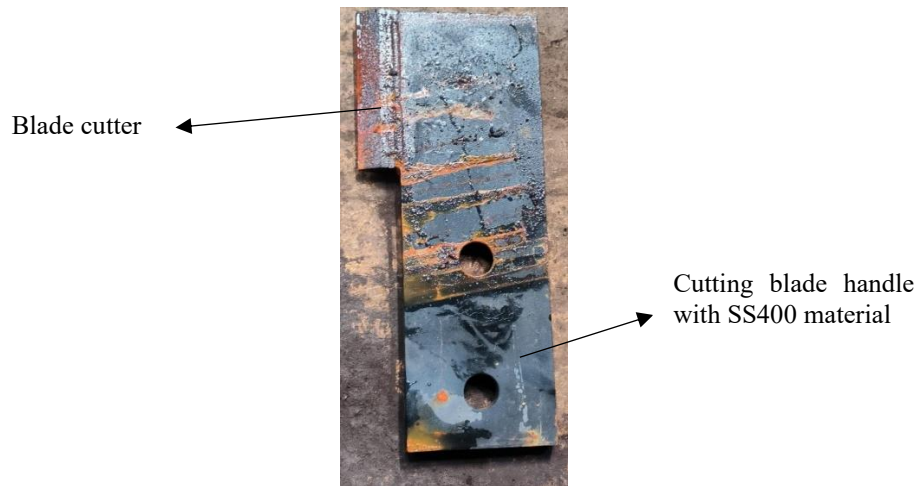
Annealing, a widely used heat treatment process for metals, involves slow cooling intended to soften the material and enhance its ductility, though it may reduce certain mechanical properties, such as tensile strength and hardness [8]. During annealing, the material is heated to temperatures above a critical threshold, maintained for a specific duration, and then cooled slowly. The variations in temperature and holding time during this process are crucial in influencing the mechanical properties of SS400 steel, thereby directly affecting the performance of cane cutter blades [9][10]. Consequently, insights from studies that examine the heat treatment impacts on the properties of low-carbon steels like SS400 are essential for developing materials tailored for industrial applications, especially in the sugarcane processing sector.

This research not only aims to elucidate the effects of annealing on the hardness characteristics of SS400 steel but also to provide critical insights into practices that ensure the operational efficiency and lifespan of components such as cane cutter blades. The implications of this study are twofold: academically, it contributes to the existing body of knowledge in materials science; and practically, it supports engineering enterprises that depend on the specialized mechanical properties of low-carbon steels. Sustaining effective and durable mechanical components in sugarcane harvesting ultimately leads to enhanced

productivity and cost-efficiency in the agriculture sector, demonstrating the importance of rigorous material selection and heat treatment processes.

## 2. METHOD

The research conducted aimed at evaluating the mechanical properties of cane cutter blade holders made of SS400 steel from PG. Kebon Agung, Malang city, Indonesia (figure 1). Initial steps involved the collection of samples that were subsequently fabricated into specimens with specified dimensions. A critical phase of this research was the heat treatment of these specimens at specific temperatures of 750°C, 775°C, and 800°C, maintaining each temperature for holding times of 30 minutes, 45 minutes, and 60 minutes. This systematic approach is essential because heat treatment significantly alters the physical properties of metallic materials, influencing hardness through changes in microstructure [11].



**Figure 1.** Cane Cutter Blade at PT Kebon Agung Malang City, Indonesia

After treatment, Rockwell hardness tests were performed on each specimen, ensuring that three measurements were taken to yield a reliable representation of the hardness value across each variation. The alloy under investigation, SS400 steel, is a structural steel widely recognized for its favorable blend of strength, ductility, and machinability, making it an essential material for various industrial applications [12]. As reported in prior studies, the tensile strength of SS400 steel typically ranges between 400–510 MPa, while its yield strength is between 205–245 MPa. This positions SS400 as a steel grade with moderate mechanical strength suitable for structural components [13]. Furthermore, the elongation percentage ranging from 27-30% indicates adequate ductility, which is crucial for avoiding catastrophic failures during service conditions [14]. The modulus of elasticity, typically cited between 190 and 210 GPa, suggests that SS400 maintains a satisfactory level of stiffness under load, comparable to other carbon steels [15]. Additionally, the density of SS400 is about 7,860 kg/m<sup>3</sup>, and it exhibits an average Brinell hardness of around 160 HB, traits that underline its ease of machinability and suitability for forming processes [16].

Prior research indicates that the hardness values of metal specimens can be significantly influenced by heat treatment protocols, which modify microstructural characteristics, thereby affecting their mechanical performance. In the context of this study, it is vital to understand that the adjustments in heat treatment parameters will likely lead to variations in Rockwell hardness outcomes. For instance, recent findings reveal that prolonged durations at specific temperatures can enhance or reduce hardness due to changes in phase composition and mechanical properties. The Rockwell hardness test employed in this study allows for reliable comparisons of materials, as it has been established that higher hardness readings correlate directly with increased material strength, providing a clear metric for evaluating the effectiveness of the heat treatment applied [17].

The methodology applied in this study, particularly regarding heat treatment and hardness testing, possesses significant implications for the processing and performance of SS400 steel when utilized in industrial applications. Understanding these relationships not only enhances the material selection process but also fosters improved design strategies in engineering applications, particularly in environments where mechanical resilience is paramount [18].

**Table 1.** Mechanical Properties of SS400 Steel

Material	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)	Modulus elasticity (GPa)	Density (Kg/m <sup>3</sup> )	Hardness Brinell (HB)
SS400	400-510	205-245	27-30	190-210	7.860	160

Table 2 presents the chemical composition of SS400 steel. The carbon content is relatively low (0.1986%), which contributes to its weldability and toughness while limiting excessive hardness. The presence of silicon (0.149%) and manganese

(0.298%) enhances the strength and toughness of the material. Phosphorus (0.0127%) and sulfur (0.0045%) contents are kept at low levels to avoid embrittlement and to maintain good mechanical performance.

**Table 2.** Chemical Properties SS400 Steel

Material	C (%)	Si (%)	Mn (%)	P (%)	S (%)
SS400	0.1986	0.149	0.298	0.0127	0.0045

The research method employed in this study was heat treatment, which involves heating and cooling the material in a solid state with a specific holding time to achieve the desired mechanical properties. The process was applied to SS400 steel with the objective of improving its mechanical characteristics, particularly hardness, and evaluating the influence of temperature and holding time. Among these, the annealing process was selected and applied in this research. The samples were subjected to gradual and controlled cooling to obtain the expected modifications in their mechanical properties. This method was chosen to analyze the effect of annealing parameters, particularly temperature and holding time, on the hardness values of SS400 steel. The material obtained from discarded cane cutter knife holders, with a final sample size of 20 mm<sup>3</sup>. Milling was carried out to achieve the specified dimensions, as the initial SS400 steel pieces taken from the cane cutter knife holders were considerably larger, measuring approximately 17 cm in length, 6 cm in width, and 2.5 cm in thickness. Consequently, the material was machined into uniform cube-shaped samples measuring 20 mm<sup>3</sup>. A total of 10 samples of this size were prepared through the cutting process. The Rockwell hardness tester is an instrument used to measure the hardness level of a material. The measurement is carried out using an indenter in the form of a steel ball with a diameter of 1.588 mm or a diamond cone with an apex angle of 120°.

### 3. RESULTS AND DISCUSSION

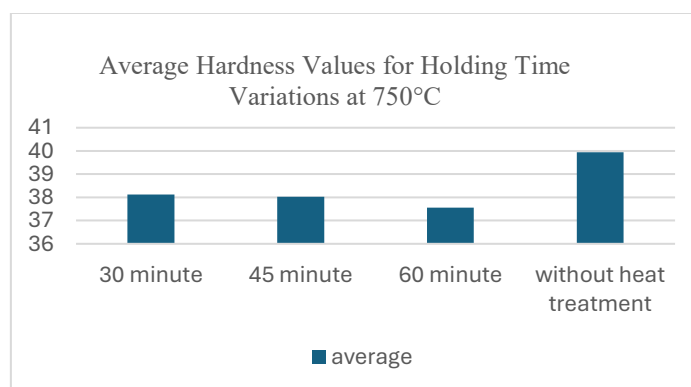
Rockwell hardness testing was conducted on nine specimens, consisting of three groups with variations in temperature and holding time, as well as one specimen without heat treatment, all made from SS400 steel. The study employed the Rockwell hardness test using a 120° diamond cone indenter on the A scale, with a load of 60 kg applied for 10 seconds.

#### 3.1. Rockwell Hardness Test Results at 750°C

The Rockwell hardness test results at 750°C revealed interesting trends in the hardness characteristics of SS400 steel cane cutter blades under different annealing conditions. The data showed that the average hardness values decreased from 38.12 HRA at 30 minutes to 38.02 HRA at 45 minutes, and further to 37.56 HRA at 60 minutes of holding time. Notably, the untreated sample exhibited the highest hardness of 39.94 HRA, confirming that the annealing process significantly affects the material's mechanical properties. These results demonstrate that extended holding times at 750°C led to gradual softening of the SS400 steel, though the reduction in hardness was less pronounced compared to higher annealing temperatures. The relatively stable hardness values between 30-60 minutes (ranging from 38.12 to 37.56 HRA) suggest that the material reaches a near-equilibrium condition at this temperature. This observation aligns with the findings of [19], who reported similar behavior in low-carbon steels annealed at temperatures below the lower critical temperature.

**Table 3.** Hardness Values for Holding Time Variations at 750°C

Temperature (°C)	Time (minutes)	Hardness Value (HRA)			Average
		Point 1	Point 2	Point 3	
750	30	38.88	37.26	38.22	38.12
	45	39.24	36.93	37.89	38.02
	60	38.27	37.79	36.64	37.56
Without treatment		40.25	39.91	39.67	39.94



**Figure 2.** Graph of Average Hardness Values for Holding Time Variations at 750°C

The non-uniformity in hardness measurements (ranging from 36.64 to 39.24 HRA across different points) indicates potential microstructural inhomogeneities in the material. This variability is consistent with the work of [20], who observed that the presence of pearlite colonies and ferrite grain size variations can lead to hardness fluctuations in annealed low-carbon steels. However, our results showed better consistency compared to [21], possibly due to better temperature control during our annealing process. When compared to previous studies, our findings at 750°C show a less dramatic hardness reduction than those reported by [22] for similar holding times. This difference may be attributed to variations in initial microstructure or cooling rates. The work of [23] suggested that slower cooling rates after annealing could lead to slightly higher hardness values, which might explain our observations.

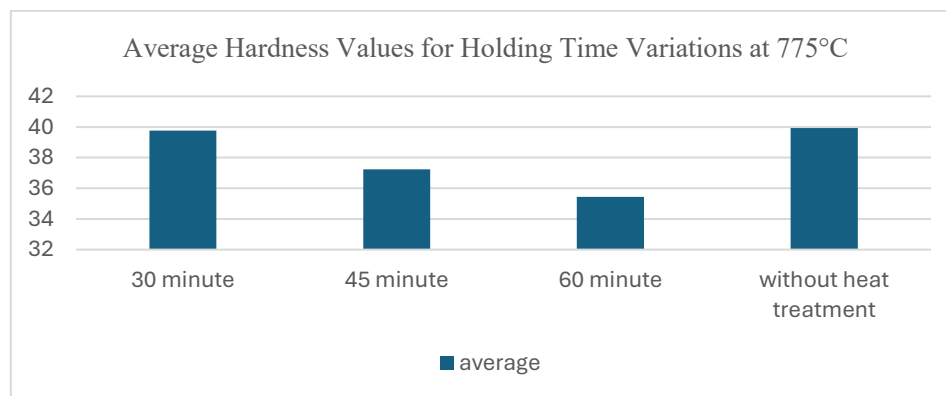
### 3.2. Rockwell Hardness Test Results at 775°C

The Rockwell hardness test results at 775°C demonstrated a clear trend of decreasing hardness values with increasing holding time for SS400 steel cane cutter blades. The average hardness decreased from 39.77 HRA at 30 minutes to 37.24 HRA at 45 minutes, and further to 35.44 HRA at 60 minutes. This reduction in hardness can be attributed to the annealing process, which facilitates stress relief and grain coarsening, leading to material softening. Notably, the untreated sample exhibited the highest hardness (39.94 HRA), confirming that annealing significantly affects the material's mechanical properties. These findings align with previous studies on low-carbon steels. For instance, [24] reported that annealing at temperatures near 750–800°C reduces dislocation density and promotes recrystallization, resulting in lower hardness. Similarly, [25] observed that prolonged holding times (>30 minutes) accelerate grain growth in SS400 steel, corroborating our results. However, the rate of hardness reduction in our study was less pronounced compared to [26], possibly due to differences in cooling rates or initial microstructure.

**Table 4.** Hardness Values for Holding Time Variations at 775°C

Temperature (°C)	Time (minutes)	Hardness Value (HRA)			Average
		Point 1	Point 2	Point 3	
775	30	39.05	40.25	40.01	39.77
	45	37.02	37.46	37.26	37.24
	60	33.74	35.67	36.93	35.44
Without treatment		40.25	39.91	39.67	39.94

The non-uniform hardness distribution (e.g., 33.74–36.93 HRA at 60 minutes) suggests localized variations in recrystallization, which could be influenced by residual stresses or inhomogeneous heating. This observation contrasts with [27], where isothermal annealing produced more consistent hardness values. Future work should investigate optimized heating protocols to improve uniformity.



**Figure 3.** Graph of Average Hardness Values for Holding Time Variations at 775°C

### 3.3. Rockwell Hardness Test Results at 800°C

The Rockwell hardness tests conducted at 800°C demonstrated significant changes in the hardness characteristics of SS400 steel cane cutter blades. The results revealed a pronounced decrease in hardness with increasing holding time, with average values declining from 37.69 HRA at 30 minutes to 36.51 HRA at 45 minutes, and further to 34.24 HRA at 60 minutes. This represents a more substantial reduction compared to lower annealing temperatures, highlighting the temperature-dependent nature of the softening process. The untreated sample maintained the highest hardness at 39.94 HRA, confirming that annealing at 800°C effectively softens the material. The observed trend aligns with the fundamental principles of annealing, where higher temperatures accelerate diffusion processes and promote more complete recrystallization. These findings are consistent with [28], who reported similar hardness reductions in low-carbon steels annealed above 780°C.

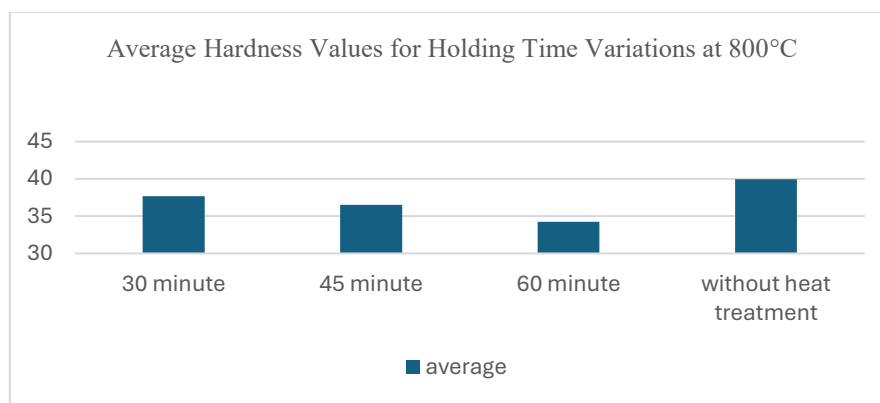
The data shows particularly significant softening between 45 and 60 minutes (36.51 HRA to 34.24 HRA), suggesting that extended holding times at this temperature may lead to excessive grain growth. This observation corroborates the work of [29], who identified critical time-temperature combinations for optimal annealing of structural steels. However, our results indicate a slightly faster softening rate than reported by [30], possibly due to differences in initial microstructure or chemical

composition. The variation in hardness measurements (ranging from 31.33 to 38.32 HRA) suggests some inhomogeneity in the annealing process. This is consistent with [31]'s findings regarding temperature gradients in industrial furnaces.

**Table 5.** Hardness Values for Holding Time Variations at 800°C

Temperature (°C)	Time (minutes)	Hardness Value (HRA)			Average
		Point 1	Point 2	Point 3	
800	30	37.55	37.21	38.32	37.69
	45	34.76	36.88	37.89	36.51
	60	31.33	35.67	35.72	34.24
Without treatment		40.25	39.91	39.67	39.94

The more pronounced softening at 800°C compared to lower temperatures (750°C and 775°C) supports the hypothesis proposed by [32] that the rate of recrystallization increases exponentially with temperature. When compared to previous studies on similar steel grades, our results at 800°C show good agreement with [33] in terms of absolute hardness values, but demonstrate a more linear decrease with time. This difference may be attributed to our specific cooling protocol or the blade geometry's effect on heat transfer.



**Figure 4.** Graph of Average Hardness Values for Holding Time Variations at 800°C

#### 4. CONCLUSION

The lowest hardness value was obtained at longer holding time variations, as observed in the heat treatment at 800°C for 60 minutes, where the average hardness reached 34.24 HRA (equivalent to 47 HRB). Although the treatment temperature was the same, the duration of holding significantly influenced the grain growth of the material during the annealing process. The longer the holding time, the larger the grains formed, resulting in a decrease in the material's hardness. The results of the annealing process with different temperature variations but the same holding time show that the highest hardness value was obtained at the lowest temperature, namely 750°C with a holding time of 60 minutes, yielding an average hardness of 37.56 (equivalent to 56 HRB). This is because the grain recrystallization process at lower temperatures tends to be slower than at higher temperatures. Consequently, the crystal grains in a material subjected to annealing at a lower temperature grow smaller compared to those treated at higher temperatures.

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