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The Effect of Nozzle Distance and Transverse Speed of the Flame Hardening Process on Hardness Values in Low Carbon Steel

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Abstract **- Flame hardening is a simple and low-cost surface modification method for increasing the local hardness of knifes product. The mechanical strength yield from manual flame hardening is defective and not uniform. This study investigates the effect of the flame oxy-acetylene nozzle transverse speed on the hardness of quenched chopper knife made low carbon steel. The firing distance of the nozzle was set to achieve the austenite temperature of low-carbon steel. Microstructure testing was carried out to analyze microstructural changes. The results show that the higher nozzle speed caused lower temperature heating and caused incomplete austenization. Incomplete austenization caused low hardness of the chopper knife, and the product didn't meet the standard hardness value.**

Keywords: surface treatment, flame hardening, low carbon steel, vickers hardness, microstructure.

I. INTRODUCTION

Flame hardening is a useful process that can be applied easily to extend the life of many machine parts. The fire hardening process is a metal surface modification technique with advantages such as hardening the surface in the selected local area, a relatively simple and easy operation method compared to other methods, relatively high processing speed, low processing costs, and can improve mechanical properties. [1, 2]. Flame hardening is widely used in various fields, including surface hardening processes for steam and gas turbine components. Utilization-related research is focused on increasing surface hardness and automation of the flame hardening process and residual stress. Residual stress produced by flame hardening is caused from tensile stress due to phase transformation and compressive stress from thermal force. [1,3-6]. Flame hardening effectively changes the microstructure and obtains an improved micro hardness [2].

The variable of the flame hardening process yield variation in the hardness depth and residual stress. Cooling time, cooling medium and the distance between the part and the flame significantly change the micro hardness and metallurgical properties. The researchers report that austenization temperature at 850^{o}C to 950^{o}C offers attractive hardness values and residual stresses for carbon steels. Incorrect selection of parameters for flame hardening reflects outputs such as brittle fracture formed, stress corrosion cracking, and fatigue failure. Low carbon steel mainly contains ferrite, and this ferrite phase offers excellent machinability characteristics compared to other medium carbon steels [6].

Surface hardening provides protection from erosion and corrosion of the surface. Higher hardness on the surface provides protection for materials on the inside which have lower hardness but have better toughness and ductility [7-10]. Uniformity in fire hardening of steel material is very important, so the process must be monitored properly and carefully in order to avoid the potential for various process failures [11-14].

In Indonesia's small-scale agricultural equipment industry, the flame hardening process is still done manually by the operator and with makeshift equipment. As in the manufacture of chopping blades installed on the organic fertilizer chopper machine. An organic fertilizer chopper is a chopping machine to cut fibrous organic matter in the form of plants/plants left over from agricultural products such as straw into smaller pieces. Figure 1 shows the blades of the organic fertilizer chopper blade.

The manufacturing of the chopper blade by manual fire hardening process causes the poor quality of the chopper blades. The chopper blade wears out quickly. Some factors that cause failures that often occur in the industrial world are material selection errors, poor component maintenance, and component design errors [10].

This study analyzes the operator's parameters in manually flame hardening on the blade chopper manufacture. The data will use to design automatically flame hardening process.

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Figure 1: Blade of organic fertilizer chopper

II. MATERIALS AND METHODOLOGY

The study used low carbon steel. Table 1 shows the composition of the material, and the composition show that the material complies with AISI 1026 Carbon steel.

Table 1: Composition of materials element

Element	(wt%)
C	0.24
Si	0.32
Mn	0.62
Cr	0.31
P	<0.01
S	0.31

The specimen's geometry was made according to the size of the organic fertilizer chopper blade. The flame hardening process was carried out at one end at a distance of 10 mm from the edge. Figure 2 shows the specimen geometry. Four thermocouples are installed on the test object to measure temperature changes at a distance of 20mm from the blade's edge, which in Figure 2 are coded T1 to T4. The oxy acetylene flame moves from zone C to Zone A with variations in the speed of 10mm/minute, 15mm/minute, and 20mm/minute. The distance between the nozzle and the material is 30mm. The Vickers hardness test was carried out along the areas where the flame was fired into the material (points P1 to P9).

During the flame hardening, the temperature at points T1 to T4 is recorded in the data acquisition. Recording temperature has been done until specimens were quenched by water. Temperatures T1 to T4 will be compared with the Ac3 temperature (critical temperature) obtained from the MAP software. MAP is a Material Algorithm Project developed by Cambridge University. The data processing uses a Neural Network in the form of data that has been processed. This study uses MAP software to determine Ac_3 in the material according to its composition.

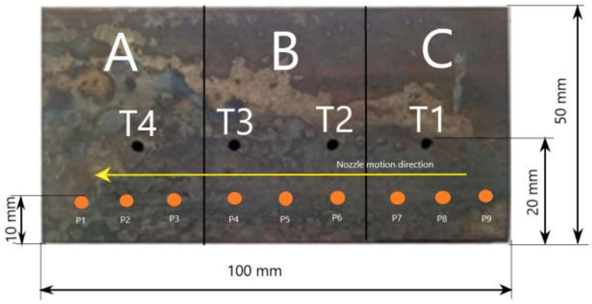

Figure 2: Specification of organic fertilizer chopper blade for testing process

The points P1 to P9 in areas A, B, and C of quenched specimens were then hardness tested by Vickers hardness method. Vickers hardness of quenched samples then compares with the hardness of untreated material. Areas A, B, and C represent the distribution of hardness on the surface of the material after flame hardening treatments. The test points in area A are the parts exposed to heating before quenching, point B and C are materials that have experienced a decrease in temperature after heating.

The metallography test was conducted to determine the microstructure. Microstructure examination was done in materals before the flame hardening process and after the flame hardening process. Microstructure analyses were used to measure the amount of % pearlite and ferrite.

III. RESULTS AND DISCUSSION

Based on the results of the material composition test in Table 1, the prediction of the Ac_3 temperature is shown in Table 2. This prediction is used to compare whether a given nozzle speed will reach the temperature of the Ac_3.

Table 2: Prediction of Ac_3 temperature on Test Material with MAP

Ac_3Temperature (^oC)	*Heat Rate* (^oC/s)
882	10
887	15
892	20

The results of the Ac3 prediction of the specimen material with a thickness 10 mm is 882 ^oC with a heating rate of 10 ^oC/s. To obtain the martensite microstructure, heating up to the Ac_3 point is required. The critical temperature (Ac_3) of mild steel material was 790-910 with 3 variations of heat rate [15].

3.1 Effect of nozzle speed on temperature at T1 to T4

Figure 3 shows the effect of speed nozzle movement on temperature during quenching on a specimen with a thickness

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of 10 mm and a heating nozzle distance of 30 mm. In Figure 3, T4 has the highest temperature, T4 position is the last contact between the heats generated from the nozzle flame before it was quenched. The temperature decreases at the T3, T2, and T1 because of the longer cooling time. The results of a thickness of 10 mm are in accordance with the experimental results of Umar et.al which stated that the maximum temperature occurs at the end in the contact area between the heat and the workpiece [15]. The slower the nozzle speed and the closer the nozzle distance, the higher the temperature [16].

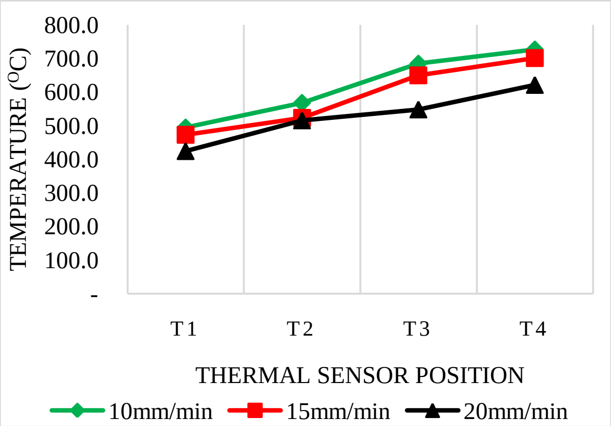


Figure 3: Effect of speed of nozzle movement on temperature distribution during quenching

The temperatures achieved were at speeds of 10 mm/min, 15 mm/min, and 20 mm/min bellow the Ac3 temperature. It was caused that the distance from the nozzle to the workpiece is still too far and the speed of the nozzle is still too fast. This indicates that the work procedure of the operator working on the flame hardening process has not been able to produce conditions that reach the Ac_3 temperature.

3.2 Effect of nozzle speed variation on the hardness

Figure 4 shows the effect of nozzle movement speed on the hardness of 10 mm thickness specimens. The distance between the nozzles with the specimen is 30 mm. The hardness at the 1 cm test point (P1) has the highest hardness value. It is because, at the P1 position, it is the last contact between the heat from the nozzle before quenched so that it has not been cooled. The hardness value decreases from the point of 2 cm (P2) to the point of 9 cm (P9) because longer cooling process.

The hardness of the test material before treatment is 150 HV. The highest hardness is in the specimen with a nozzle speed of 10 mm/min, which is 503 HV at point P1. This hardness value is still below the standard value of SNI for Hammer Mill knife blade hardness. The standard hardness value for hammer mill blades, according to SNI (Indonesian National Standard) 7590:2011, is 51.2 HRC or 540 HV.

This hardness illustrates that there is a correlation where the heating temperature before quenching that does not meet the Ac_3 temperature will result in a hardness value that is not maximal, even though the hardness value increases from the hardness value before the process. Figure 4 also shows that the heating and quenching pattern will produce hammer mill blades that have various hardness values in the hardened area, where the variation in hardness values is up to 200 HVN.

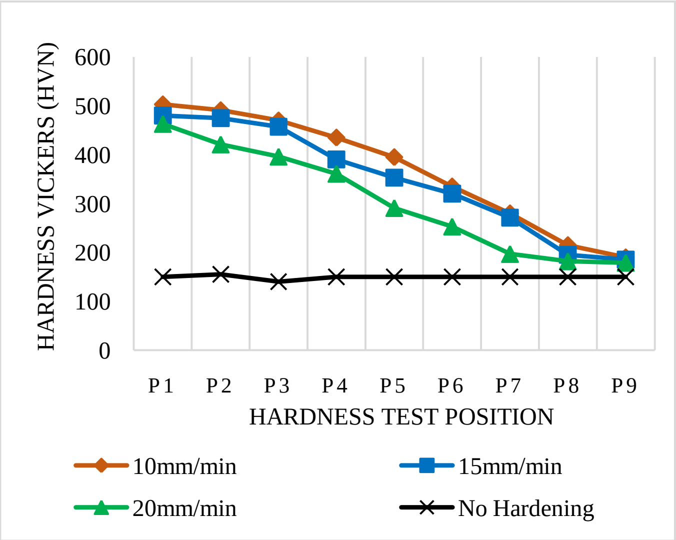
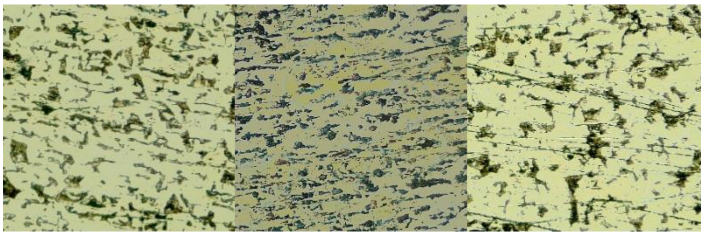


Figure 4: Effect of nozzle movement speed on hardness

3.3 Microstructure of Materials before Flame Hardening Process

Microstructure examination is carried out to compare the structure of the material before the hardening process with the structure of the material that has the highest hardness value. In the material that has not been treated, the material has a hardness value of 150 HV. The micrographic photo of the area can be seen in Figure 5. In Figure 5 the light colored area is Ferrite and the dark colored part is pearlite. In the area of the test material, that experienced the highest increasing hardness from 161HV to 503HV. The results of micrographic photos of this area are shown in Figure 6. A comparison of Figure 5 and Figure 6 shows more dark areas or pearlite. This shows that the rapid heating and cooling process carried out caused increasing in the pearlite phase in the material.



(a) (b) (c)

Figure 5: Micrograph before heat treatment (a) 10 mm 10 mm/m (b) 10 mm 15 mm/m (c) 10 mm 20mm/m

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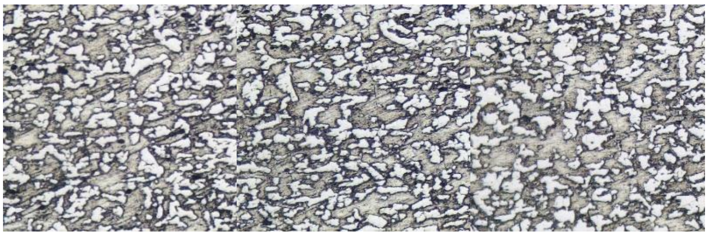
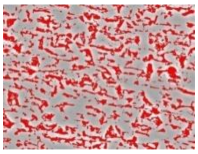
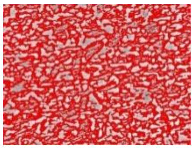
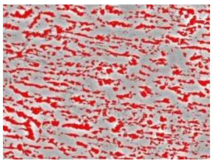
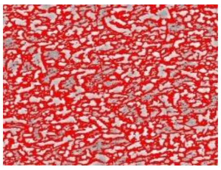
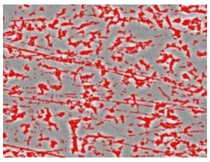
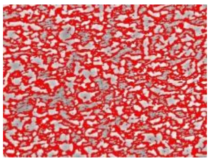


Figure 6: Micrograph after heat treatment (a) 10 mm 10 mm/m (b) 10 mm 15 mm/m (c) 10 mm 20mm/m

The results of the analysis using image J software on the material before and after the flame hardening process are shown in Table 3. The highest pearlite growth occurred in a material with a thickness of 10 mm, heating nozzle distance of 30 mm, and speed of nozzle movement of 10 mm/m. The hardness increased by 30.11%. According to the highest hardness value, reaching 503 HV. This shows that the more pearlite, the material will be harder.

Table 3: Pearlite growth flame hardening specimen

No	Before Hardening	After Hardening	Perlite Growth (%)
1	10mm/min  22,62%	10 mm/min  52,73%	30,11%
2	15mm/min  22,47%	15 mm/min  47,27%	24,80%
3	20mm/min  22,17%	20 mm/min  43,71%	21,54%

IV. CONCLUSION

The speed of the nozzle movement affects the austenite temperature before the quenching process. The faster the nozzle movement rate, the lower the maximum temperature achieved. The effect of the austenite temperature achieved will affect the hardness value obtained. Temperatures below the austenite temperature will produce low hardness values. The method of regulating the speed of the nozzle movement and the selection of the method and time of quenching affects the temperature during quenching and the amount of perlite growth.

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