The Effect of Speed and Distance on the Achievement of Austenitization Temperature in Low Carbon Steel with Thickness Variations on the Flame Hardening Process

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Abstract. Austenite temperature must be achieved in the surface hardening process. In the process of surface hardening by the method of flame hardening, failure is often encountered, for example, such as increasing the value of hardness that is not optimal, and the value of hardness that is less uniform The type of fire used, the distance of fire to the specimen, the speed of fire and the level of thickness of the material are factors that are very influential in the process of flame hardening. The purpose of this study is to measure and observe the profile or rate of the trend of increase and decrease in temperature in the flame hardening process in low carbon steel material. The experiment method that is carried out is by giving the variation of the rate. The measurement process uses several thermocouples mounted on the specimen and connected to a computer for the process of data recording and process monitoring. The conclusion of this study is the greater the value of the thickness of low carbon steel material that is processed by flame hardening, so to reach the temperature of austenitization by the method of flame hardening the speed of fire must be slowed. An improper combination between the distance of fire and specimens and the speed of fire can cause austenite temperature not to be reached. The heat reduction rate takes place more slowly than the rate of increase in heat the speed of fire and distance of fire to low carbon steel which has varying levels of thickness.

1. Introduction

The value of surface hardness in metals, for several reasons, is often sought to be increased. One area that utilizes the surface hardening process a lot is the metal industry for agricultural equipment. In Indonesia, there are quite a number of small and medium-sized metal industries (IKM) engaged in the manufacture of agricultural equipment. One of the problems faced by metal IKM is quality problems related to the surface hardness value of their products. One of the quality references for agricultural equipment products is the Indonesian National Standard (SNI).

SNI requires that the surface hardness value meets at least three criteria, namely the hardness value meets the minimum limit, the level of hardness that is evenly owned in the specified area and the third
is for some products such as knives, the hardness value and the level of hardness must be met in one third of the product surface area.

IKM that use the surface hardening method with the flame hardening method with oxy-acetylene welding machines have problems to meet SNI standards. The value of violence can be achieved but the level of uniformity in the value of violence in the area required cannot be met. Covering one-third of the area must have a violence value according to SNI standards is also a problem in itself. This is further complicated when materials have different thickness levels.

Flame hardening process is a useful technique for a surface modification that can be readily applied to extend the service life of many machine steel parts. Such various applications are brought about by the ability to harden regions locally, the simple and easy operation, the high-speed and low-cost processing, and the improved mechanical properties [1]. There is so many studies have been mostly focused on the improvement of hardness on the surfaces and the automation of the flame hardening process [2–5] and details on the flame hardening apparatus [6].

Several other studies related to flame hardening and specifically flame hardening in low carbon steel have been carried out by S. Sharkar et al. In particular they examined the application of lasers to this process where the analysis of temperature changes to the austenite temperature was studied in depth [7].

Studies on the process of how to achieve austenite temperatures and their characteristics for various types of materials have also been carried out such as for stainless steel materials by Y. Zhang et al. And on ultra-high strength steels by R. Veerababua et al [8,9].

This research tries to discover and explore phenomena related to the use of flame hardening in similar materials but has different thicknesses. Variations in the speed of the nozzle and the distance of the nozzle to the workpiece will also be examined for their effect on the surface hardening process. The results of this study are expected to be used as a reference for fire hardening process operators and can also be used as materials for designing automation in flame hardening by creating machines instead of human operators.

2. Materials and Methods

2.1. Materials

The test material used is the type of AISI 1026 Carbon steel (AISI, n.d.) which is included in the low carbon steel category. The following table 1 shows the chemical composition data of the test material.

| Element | Test Materials |
|---------|----------------|
|         | 6 mm (wt%) | 10 mm (wt%) |
| C       | 0,24        | 0,24        |
| Si      | 0,46        | 0,32        |
| Mn      | 0,88        | 0,62        |
| Cr      | 0,46        | 0,31        |
| P       | <0,01       | <0,01       |
| S       | <0,05       | 0,31        |

Based on the results of the ingredients composition test in Table 1, it can be determined the Ac3 temperature for each material. The temperature of Ac3 or the temperature at which the material undergoes the austenite phase as a whole can form a martensitic phase if it is cooled quickly. The Ac3 temperature can be predicted by entering material composition data into the Material Algorithm Project (MAP) application. This prediction is used to compare whether the nozzle speed of each speed variation will reach the temperature of Ac3. In Table 2 are the results of the estimated Ac3 temperature for each material. This result is consistent with Amendee's study in 1985 which stated that the Ac3 temperature of mild steel was 790-910 with three variations in heat levels [10].
Table 2. Results of prediction of $\text{Ac}_3$ temperature with MAP

| Thickness 6 mm | Thickness 10 mm |
|----------------|-----------------|
| $\text{Ac}_3$ Point ($^\circ$C) | Heat Rate ($^\circ$C/s) | $\text{Ac}_3$ Point ($^\circ$C) | Heat Rate ($^\circ$C/s) |
| 900           | 5               | 876           | 5               |
| 907           | 10              | 882           | 10              |
| 913           | 15              | 887           | 15              |
| 918           | 20              | 892           | 20              |

2.2. Methods
The process of testing the flame heating is carried out accompanied by quenching treatment with water cooling media. This test utilizes a flame from oxy-acetylene welding with a neutral flame type to heat the surface of the test specimen. The oxy-acetylene welding flame pattern can be seen in Figure 1b, i.e. go left one way. Fire is fired in the middle area between the distance of the thermocouple and the edge of the test material, or 10 mm each from the edge of the test object and from the position of the thermocouple. Thermocouple installation as in Figure 1a.

Figure 1. (a) Dimensions of the test specimen, (b) Direction of heating of the flame hardening

The testing procedure carried out is to prepare low carbon steel material with the composition as listed in Table 1. Each material is given four holes in single line position to be filled the thermocouple, where the distance of each hole is 20mm. Thermocouple coded T1, T2, T3, and T4. The line of fire from the nozzle is depicted on the material as a guide in the form of a straight line. The distance of the fire path to the thermocouple hole perpendicular is 10 mm.

The distance of the nozzle to the workpiece specimen is arranged in two variations, namely 30mm and 50mm. The speed of the moving nozzle rate is also varied ie 10mm/min, 15mm/min and 20mm/min. The thermocouple is connected to the computer directly so data can be recorded directly.

3. Result and Discussion
3.1. Temperature profile on material with a thickness of 6mm and nozzle distance to the workpiece 30mm.
Temperature profile measured by a thermocouple mounted on a material with a thickness of 6mm, a distance of 10mm from the fire line fired from the nozzle, with 30mm distances of the test specimen and with variations in the speed of the nozzle movement of 10mm/min, 15mm/min and 20 mm/min are shown in Figure 2 to Figure 4.
Figure 2. (a) Profile of temperature - time for materials with a thickness of 6mm, nozzle distance of 30mm and nozzle velocity of 10mm / min. (b) the temperature when quenching.

Figure 2 is a profile of temperature versus time for a material with a thickness of 6mm, nozzle distance of 30mm and nozzle velocity of 10mm / min. The highest and lowest temperatures at T1 are 40°C at 1st second and 863.2°C at 190th seconds. The position of the T4 sensor is located at the end of the heating nozzle so it has the highest temperature of 826.5°C. Then the temperature drops further on the T3 and T2 sensors while the sensor position T1 is the initial position of the nozzle so that it has the smallest temperature which is 693.6°C because in the T1 section it has cooled with the longest time.

Figure 3 is the temperature profile of a material with a thickness of 6mm, the distance of the nozzle to the test object by 30mm and the velocity of the nozzle to 15mm / min. The highest and lowest temperature at T1 is 30°C at the 1st second and 872°C at the 130th second. The temperature at which the material is quenched at the 400th second is shown in Figure 3b. The T4 sensor position is the last closest position to the flame which has the highest temperature of 785.6°C. The temperature decreases further on the T3 and T2 sensors and the lowest is at T1 where the measured temperature is 667.8°C.

Figure 4 is a plot of the temperature profile on the material with a thickness of 6mm with a spacing of 30mm with a nozzle speed of 20mm / min.
The highest and lowest temperature at T1 is 47.4°C at the 1st second and 810°C at the 75th second. The temperature when the material is quenched at the 300th second is shown in Figure 4b. At position T4 which is located at the end of the heating process has the highest temperature of 724.2°C. T1 is the sensor at the initial position of the nozzle so that it has the lowest temperature of 630.7°C.

3.2. Temperature profile on material with a thickness of 6mm and nozzle distance to the workpiece 50mm.

Temperature profile measured by a thermocouple mounted on a material with a thickness of 6mm, a distance of 10mm from the fire line fired from the nozzle, with 50mm distances of the test specimen and with variations in the speed of the nozzle movement of 10mm/min, 15mm/min and 20mm/min are shown in Figure 5 to Figure 7.

Figures 5a and 5b below are the results of the plot of the material temperature profile which has a thickness of 6mm and the distance of the nozzle to the test specimen is 50mm with a nozzle speed of 10mm/min.

The highest and lowest temperatures at T1 are 32°C at the 1st second and 659.4°C at the 110th second. The temperature at which the material is quenched at the 600th second will be shown in Figure 5b. The temperature reads at T4 which is 663.5°C. Then the temperature at the sensor position T4 is the initial position of the nozzle so that it has the smallest temperature which is 385.2°C because in the T1 section it has cooled with the longest time.

Figures 6a and 6b below are the results of the plot of the material temperature profile which has a thickness of 6mm and the distance of the nozzle to the test specimen is 50mm with a nozzle speed of 15mm/min.
Figure 6. (a) Profile of temperature - time for materials with a thickness of 6mm, nozzle distance of 30mm and nozzle velocity of 15mm / min. (b) the temperature when quenching.

The highest and lowest temperature at T1 is 41.7°C at the 1st second and 650°C at the 110th second. The temperature at which the material is quenched at the 400th second will be shown in Figure 6b where the temperature measured by the T4 sensor is 632°C and T1 which has the lowest temperature of 365.9°C.

Figures 7a and 7b below are the results of the plot of the material temperature profile which has a thickness of 6mm and the distance of the nozzle to the test specimen is 50mm with a nozzle speed of 20 mm/min.

Figure 7. (a) Profile of temperature - time for materials with a thickness of 6mm, nozzle distance of 50mm and nozzle velocity of 20mm / min. (b) the temperature when quenching.

The highest and lowest temperature at T1 is 72.9°C at the 1st second and 626.5°C at the 94th second. The temperature when the material is quenched is at the 300th second, at the T4 sensor position, the measured temperature is the highest temperature at 587°C. the lowest temperature measured by the T1 sensor is 368.9°C.

3.3. Temperature profile on material with a thickness of 10mm and nozzle distance to the workpiece 30mm.

Temperature profile measured by a thermocouple mounted on a material with a thickness of 10mm, a distance of 10mm from the fire line fired from the nozzle, with 30mm distances of the test specimen and with variations in the speed of the nozzle movement of 10mm/min, 15mm/min and 20 mm/min are shown in Figure 8 to Figure 10.

Figures 8a and 8b below are the results of the plot of the material temperature profile which has a thickness of 10mm and the distance of the nozzle to the test specimen is 30mm with a nozzle speed of 10 mm/min.
Figure 8. (a) Profile of temperature - time for materials with a thickness of 10mm, nozzle distance of 30mm and nozzle velocity of 10mm / min. (B) the temperature when quenching.

The highest and lowest temperatures at T1 are 32°C at the 1st second and 632.5°C at the 94th second. The temperature when the material is quenched is at the 600th second, at the T4 sensor position, the highest temperature measured is 726.8°C. At the T1 sensor position, the measured temperature is the smallest temperature, which is 494.6°C.

Figures 9a and 9b below are the results of the plot of the material temperature profile which has a thickness of 10mm and the distance of the nozzle to the test specimen is 30mm with a nozzle speed of 15 mm/min.

Figure 9. (a) Profile of temperature - time for materials with a thickness of 10mm, nozzle distance of 30mm and nozzle velocity of 15mm / min. (b) the temperature when quenching.

The highest and lowest temperature at T1 is 44°C at the 1st second and 575°C at the 124th second. The temperature when the material is quenched is at the 400th second on the T4 sensor, the measured temperature is the highest temperature that is 701.1°C. At T1 Sensor the measured temperature is the smallest temperature that is 424°C.

Figures 10a and 10b below are the results of the plot of the material temperature profile which has a thickness of 10mm and the distance of the nozzle to the test specimen is 30mm with a nozzle speed of 20 mm/min. Suhu tertinggi dan terendah pada T1 adalah 44°C pada detik ke-1 dan 501°C pada detik ke-116. Suhu saat material di quenching yaitu pada detik ke-300, pada posisi sensor T4 terbaca memiliki suhu paling tinggi yaitu 621,3°C. Pada posisi sensor T1 memiliki suhu yang paling kecil yaitu 424°C.
Figure 10. (a) Profile of temperature - time for materials with a thickness of 10mm, nozzle distance of 30mm and nozzle velocity of 20mm / min. (B) the temperature when quenching.

3.4. Temperature profile on material with a thickness of 10mm and nozzle distance to the workpiece 50mm.

Temperature profile measured by a thermocouple mounted on a material with a thickness of 10mm, a distance of 10mm from the fire line fired from the nozzle, with 50mm distances of the test specimen and with variations in the speed of the nozzle movement of 10mm/min, 15mm/min and 20mm/min are shown in Figure 11 to Figure 13.

Figures 11a and 11b below are the results of the plot of the material temperature profile which has a thickness of 10mm and the distance of the nozzle to the test specimen is 50mm with a nozzle speed of 10mm/min

Figure 11. (a) Profile of temperature - time for materials with a thickness of 10mm, nozzle distance of 50mm and nozzle velocity of 10mm / min. (b) the temperature when quenching.

The highest and lowest temperature at T1 is 44°C at the 1st second and 474°C at the 178th second. The temperature when the material is quenched is at the 600th second, on the T4 sensor the measured temperature is the highest temperature of 323.5°C. On the T1 sensor the smallest temperature value measured is 198.7°C.

Figures 12a and 12b below are the results of the plot of the material temperature profile which has a thickness of 6mm and the distance of the nozzle to the test specimen is 50mm with a nozzle speed of 15mm/min.

Figure 12. (a) Profile of temperature - time for materials with a thickness of 6mm, nozzle distance of 50mm and nozzle velocity of 15mm / min. (b) the temperature when quenching.
Figure 12. (a) Profile of temperature - time for materials with a thickness of 10mm, nozzle distance of 50mm and nozzle velocity of 15mm / min. (b) the temperature when quenching.

The highest and lowest temperature at T1 is 39°C at the 1st second and 472°C at the 124th second. The temperature when the material is quenched is at the 400th second, at the T4 sensor the measured temperature is 292°C. At the T1 sensor position the smallest measured temperature is 182.2°C.

Figures 13a and 13b below are the results of the plot of the material temperature profile which has a thickness of 10mm and the distance of the nozzle to the test specimen is 50mm with a nozzle speed of 20 mm/min

Figure 13. (a) Profile of temperature - time for materials with a thickness of 10mm, nozzle distance of 50mm and nozzle velocity of 20mm / min. (b) the temperature when quenching.

The highest and lowest temperature at T1 is 51.9°C at the 1st second and 445°C at the 115th second. The temperature when the material is quenched is at the 300th second, on the T4 sensor, the highest measured temperature is 265°C. At the T1 sensor position the smallest measured temperature is 170.2°C

4. Conclusions
At the condition of the distance of the nozzle to the same test object, the speed of the nozzle's speed of movement is the same, and by using the same type of fire, then in the same material with different thickness, a different temperature increase rate will be achieved at the same position at a certain distance from the path of the fire. So that the austenite temperature is more difficult to achieve for materials that have more thickness.

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