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Survey of Microstructure after Annealing and Normalizing for C45 Steel with Small Diameter

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Abstract: In the mechanical engineering field, C45 steel with a small diameter is commonly used to manufacture load-bearing machine parts such as nuts, bolts, gear shafts, piston pins, slider bars, etc. The microstructure will help partially support the machining capabilities assessment to achieve high productivity. This article proposes to investigate the microstructure of a C45 steel sample with dimensions of $\phi 12 \times 12$ mm with different temperatures cooled in the same furnace and still air. The set of images of the microstructure of this steel sample after annealing and normalizing is the basis for choosing the heat treatment process to match the cutting regime.

Keywords: C45 steel, small diameter, annealing, normalizing, microstructure

I. INTRODUCTION

The C45 steel is widely used in the field of mechanical engineering. To achieve the microstructure for machining, the steel workpiece is subjected to heat treatment. Many studies have shown the influence of heat treatment parameters (temperature, holding time, cooling) on the microstructure. In the study [1], the authors conducted experiments with different temperatures, holding times, and cooling environments for S45C steel. The results show that temperature and cooling environment strongly affect the microstructure of this steel, leading to significant changes in hardness. In the research [2], the authors showed that the heat treatment process on alloy steel can change the material's mechanical properties without changing the alloying element in the steel. 45C8 steel has been used for high-stress testing purposes, and heat treatment procedures have been carried out to give optimum values of mechanical properties. In the article [3], the authors did experimental and numerical research on induction heat treatment applied to ISO C45 steel. Both normalized and incubated samples were considered. Process parameters are implemented in numerical code (Sysweld 2000). The purpose of this work was that the author wanted to create a thermo-metallurgical model of induction heat treatment that was tested by experimental results. The experimental results (microstructure and microhardness) will be compared with the numerical results. Thanks to the experimental data, the author obtained hardness testing and analysis results using an optical microscope. The material properties, taken by the author from the literature, and the process parameters are performed using numerical codes to determine the material's heat treatment and metallurgical history. In 2021, Mulyadi and his colleagues presented a quenching process to increase the hardness of steel when the steel has ferrite content under normal conditions for AISI 1045 steel [4]. The author performs this process by heating steel to a temperature of 850°C and cooling it quickly. The proposed heat treatment is applied in cooling environments, including still air, salt water, lubricating oil, and liquid gas. The results show that the mechanical properties of AISI 1045 steel change significantly. In the study [5], the authors took advantage of the high energy of the laser beam to quickly heat the workpiece surface to achieve the self-quenching effect. The author has shown the influence of laser surface hardening parameters, such as changes in power, scanning speed, focal length, etc. Analysis results show that laser power and scanning speed are important parameters affecting materials' hardness. Numerical results show that the proposed finite element model can simulate the process of laser surface heat treatment and the tempering effect of steel. In 2015, Ibrahim and Sayuti presented the study "Effect of Heat Treatment on Hardness and Microstructures of AISI 1045" to determine the effects of heating & cooling on hardness and microstructure [6]. The paper aims to obtain the effect of cooling rate on hardness and determine the appropriate cooling environment to get martensitic microstructure without cracking heat-resistant products. The results of the article show that the hardness value of the samples increases with increasing temperature, except at 1000℃.The authors in [7] studied the hardness of medium carbon steel, AISI 1045 steel. In this article, different cooling environments were used to improve the mechanical properties and wear resistance. The quenching process is heated at 850℃ in an electric furnace and maintained for 40 minutes until a uniform structure is achieved. The cooling media used are 90% water – 10% machining coolant, 70% water – 30% machining coolant, and 60% water – 40% machining coolant. In the article "The Effect of the Coolings on the Hardness of JIS SKH51 Steel when

Quenching" [8], the author presented the influence of the cooling environment on the hardness of SKH51 steel after quenching. The steel sample is heated in a resistance chamber furnace. The results show that the highest hardness is achieved when cooling in a NaOH environment, followed by water, oil, and air. This study aims to show the cooling environment's influence on the hardness during the quenching process of JIS SKH51 steel. Four cooling media were conducted: air, oil, water, and brine (10% NaCl). The results show that the hardness of the sample quenched in salt water environment is the highest.

In this article, the authors conducted experiments on heating C45 steel at four temperature levels (760°C, 800°C, 840°C, and 880°C), keeping the heat for about 15 minutes, and slowly cooling the furnace and the air.

II. EXPERIMENT PROCEDURE

The results of testing the chemical composition of the C45 steel sample are presented in Table 1.

Table 1 Chemical composition of the C45 steel (% weight)

C	Si	Mn	P	S	Ni	Cr	Cu	Other
0.45-0.46	0.20	0.63	<0.014	<0.006	<0.05	<0.08	<0.12	<0.13

The samples prepared with dimensions of ϕ12 × 12 mm (shown in Figure 1).

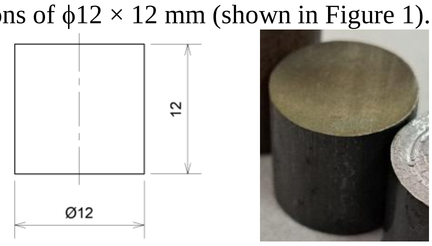

Figure 1 Experimental sample

To get results about the microstructure before and after heat treatment, the sample is taken through basic steps: grinding in the sandpaper, polishing, etching, observing on the microscope, and taking pictures.

After examining the microstructure in its initial state (shown in Figure 2), the samples were heated in the resistance chamber furnace with four temperature levels: 760°C, 800°C, 840°C, and 880°C. Heat retention time is about 15 minutes. The sample is then cooled slowly in the furnace and air.

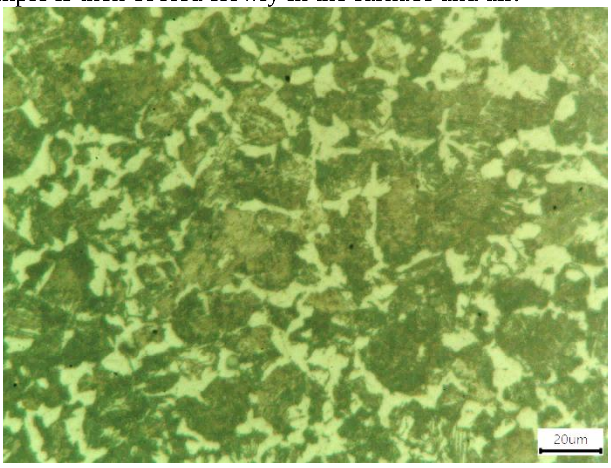

Figure 2 The microstructure of C45 steel in its initial state

III. RESULTS AND DISCUSSIONS

III.A. Microstructure of the sample after annealing

The microstructure images in Figure 3 to Figure 6 are of the samples heated at 760°C, 800°C, 840°C, and 880°Ctemperature, hold time for 15 minutes, and cooled slowly in the furnace, respectively.

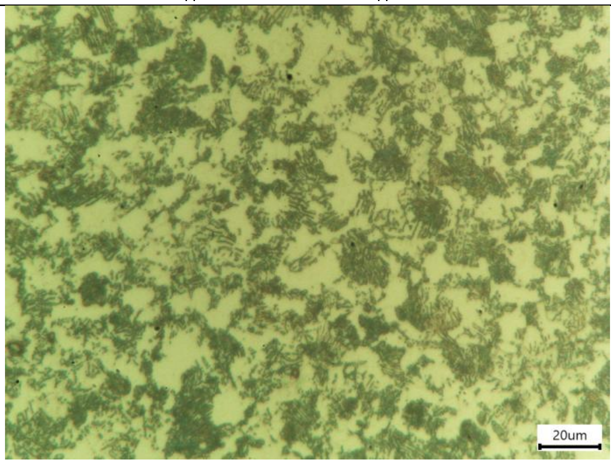

Figure 3 The microstructure of the C45 steel sample after being heated at 760°C temperature and cooled slowly in the furnace.

⇒ *Ferrite and Pearlite grains size are relatively small. The transformation of pearlite grains is not complete.*

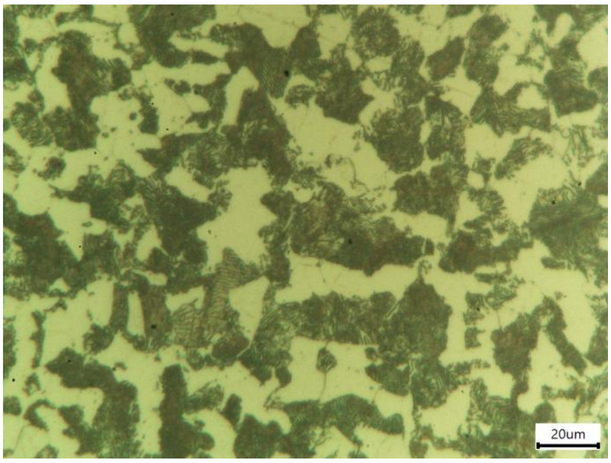

Figure 4 The microstructure of the C45 steel sample after being heated at 800°C temperature and cooled slowly in the furnace.

⇒*Ferrite and Pearlite grains have larger sizes than the results in Figure 3.*

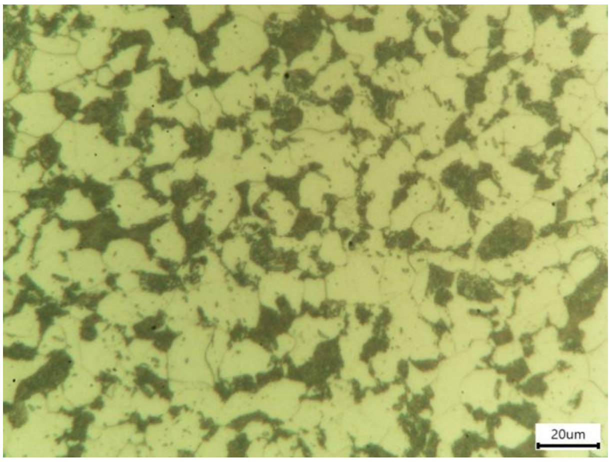

Figure 5 The microstructure of the C45 steel sample after being heated at 840°C temperature and cooled slowly in the furnace.

⇒*The size of Pearlite (black) grains is quite small. The grains are distributed relatively evenly.*

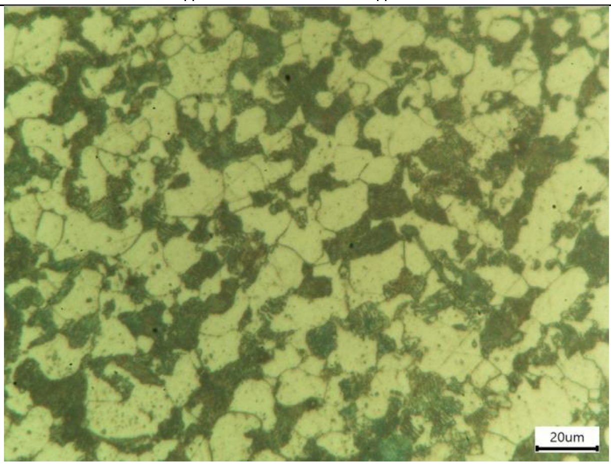

Figure 6 The microstructure of the C45 steel sample after being heated at 880℃ temperature and cooled slowly in the furnace.

⇒The size of Ferrite and Pearlite grains is small and distributed relatively evenly.

III.B. Microstructure of the sample after normallising

The microstructure images in Figure 7 to Figure 10 are of the samples heated at 760℃, 800℃, 840℃, and 880℃temperature, hold time for 15 minutes, and cooled slowly in the air, respectively.

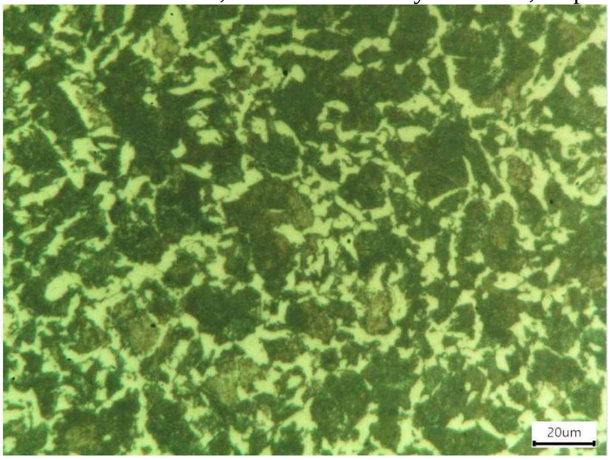

Figure 7 The microstructure of the C45 steel sample after being heated at 760℃ temperature and cooled slowly in the air.

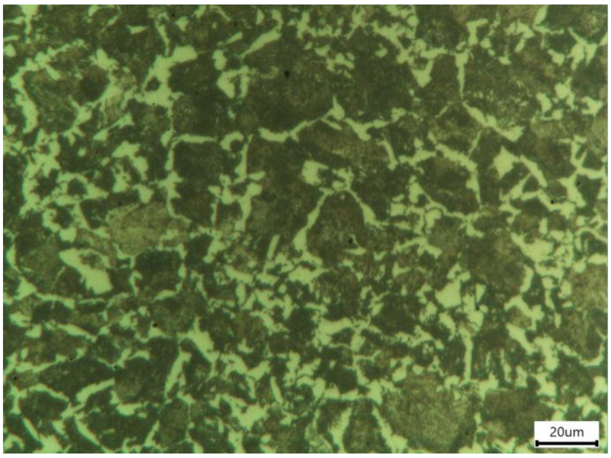

Figure 8 The microstructure of the C45 steel sample after being heated at 800℃ temperature and cooled slowly in the air.

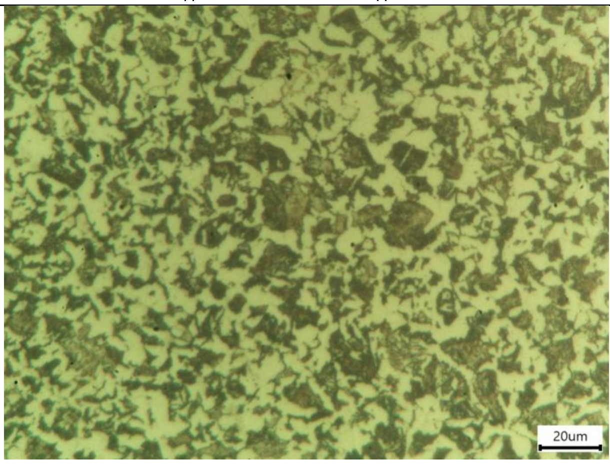

Figure 9 The microstructure of the C45 steel sample after being heated at 840℃ temperature and cooled slowly in the air.

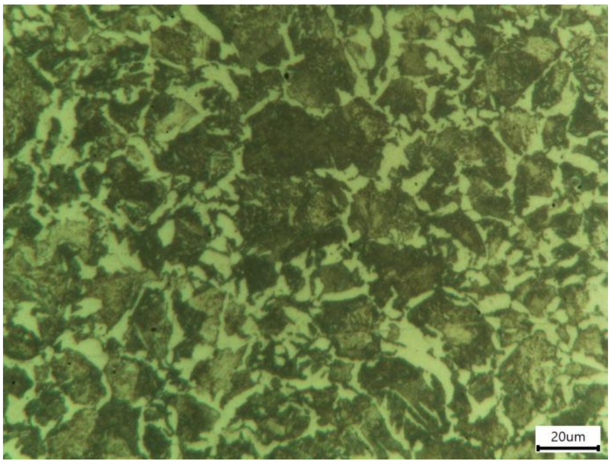

Figure 10 The microstructure of the C45 steel sample after being heated at 880°C temperature and cooled slowly in the air.

⇒The results of the microstructure of the sample after normalization at 760℃, 800℃, and 880℃ are almost the same, the Pearlite (black) grains size are quite large.
Ferrite and Pearlite grains size in the microstructure of the sample after normalization at 840℃ is small and relatively uniform distribution.

IV. CONCLUSION

This article presents the investigation of the microstructure of the C45 steel sample with the size of $\phi 12 \times 12$ mm after annealing and normalizing at different temperatures (760℃, 800℃, 840℃, and 880℃), holding time of 15 minutes. In both cases of slow cooling in the furnace and the air, the samples heated at 840℃ had small Ferrite and Pearlite grain sizes and showed a relatively uniform distribution.

V. ACKNOWLEDGEMENTS

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