Grain growth of powder metallurgy steel after heat treatment

Aminnudin*, H Suryanto, and Suprayitno
Department of Mechanical Engineering, Universitas Negeri Malang, Indonesia

*aminnudin.ft@um.ac.id

Abstract. Steel with very small grain has high strength but still have ductility. When the steel is heated to austenitic temperatures it can make the steel grains grow and reduce the hardness of the steel. To prevent this, it is necessary to know the effect of holding time on steel hardness. In this study, we examined the effect of holding time on hardness of very small grained steel. The hardness is indicating of grain growth of the steel. In this study, we examined the effect of holding time on hardness of very small grained steel. The heat treatment is carried out at 1100 degrees Celsius using an electric furnace. Micro hardness testing using the micro-Vickers method uses 300 grams of force and an indentation time of 10 minutes. Observation of microstructure is carried out with metallurgical microstructure. The etc...ing solution for microstructure observation was nital solution. Heat treatment of steel powder metallurgy with holding time of 60 minutes will cause a decrease in hardness from 261 to 207 and grain size growing from 3.2 μm to 6.3 μm

1. Introduction

The heat treatment process in steel can change the mechanical and physical properties of the steel[1]. This heat treatment process can be carried out on steels with a minimum carbon content of 0.2% [2], [3]. The heat treatment process can be done by heating the steel until the phase change occurs from the ferrite phase to the austenite phase [4]. Rapid cooling will change the phase in steel from the austenite phase to the meta-stable (martensitic) phase [5], [6].

The heat treatment process requires holding time at a certain time to make all ferrite transform to austenite. This holding time affected to the steel grain size. Very fine grain of steel could growth if exposed at high temperature for a long time [4]. The grain grows can change the mechanical properties of the steel, especially its toughness. The mechanical properties change must be prevented, since high steel carbon has very brittle.

The size of a very fine grain will increase the elasticity and strength of the steel [7]. Heating will increase the energy in steel and will make the steel grains grow.[8][9] The growth energy of this grain is obtained from the increasing temperature of the steel, the higher the temperature the greater the energy and will accelerate the process of growth of steel grains. Besides the temperature, holding time is also very influence to grain growth, the longer the heating time the larger the grain size occurs[10].

2. Methods

The metal used in this research is high carbon steel which is processed by the powder metallurgy process, the dimension of the specimens are length of 10 mm, width 10 mm and thickness of 5 mm. The chemical composition is C 1.18 %, Vanadium 3.10 %, Chrome 4.2%, Molybdenum 5.0 %, and Wolfram 6.40 %.
2.1. Heat Treatment
The heat treatment process is carried out in electric furnace. The heating process is carried out in two stages (see figure 2). The first stage the steel is heated to a temperature of 500 °C in the holding for 15 minutes, after holding in 15 minutes the temperature increased until reach 1100 °C and holds until 15, 30, 45 and 60 minutes respectively. The steel is quenched on the air.

2.2. Microstructure Observation
Steel after heat treatment is observed in its microstructure using optical microscopy. The microscope used is a metal microscope Olympus brand type GX-41 which is equipped with a digital camera. The objective lens magnification used is 40 X, and the camera adapter correction factor is 1.2 X. The total magnification used was 400 X.

The microstructure of the steel before it can be observed with a metallurgical microscope the surface of the specimens must be prepared. The preparation step of the specimen was sanded with sandpaper, polishing with the polish cloth. The size of the scrubbing paper used was 100, 200, 500, 1000 and 500 mesh respectively. This polishing process uses a sandpaper machine with a rotation speed of 300 rpm and used water for cooling media. The surface of the polished specimen was etched using a nital solution, the composition of this solution was 97% ethanol and 3% HNO3. The etching process was done by dipping the surface of the specimen for 10 seconds.

2.3. Micro-Hardness Test
The aim of Hardness measurements was to check changes in hardness due to changes its grain size. Hardness testing is carried out on specimens whose surfaces have been polished. The hardness test is carried out by the micro Vickers method which uses a diamond pyramid indenter with an seconds and a load of 300 grams force. The hard testing machine used is a micro-Vickers machine, with a load can be vary from of 50 grams to 1000 grams and the indentation can be set from 1-30 seconds.

3. Results and Discussion
The microstructure of steel after the heat treatment process with a different holding time can be seen in figure (1) and (2).

![Figure 1](image_url)

**Figure 1.** Microstructure of Steel before heat treatment (a) and after heat treatment with holding time (15 minutes)
Figure 2. Microstructure of Steel after heat treatment (a) with holding time 30 minutes, (b) with holding time 45 minutes (c) with holding time 60 minutes

From the observation of microstructure it could be seen that the grain of the steel was changed and the size of the grain was growth. Grain size grows from 3.2 before the heat treatment process to 6.3 after the heat process with a holding time of 60 minutes.

Holding Time Vs Grain Size

Figure 3. Holding time Effect To Grain Size
The grain size grows according to holding time. This shows the growth of grain caused by the energy obtained from the temperature rise. The higher energy on the steel made the grain growth larger [11]. Increasing the size of this grain will reduce the hardness of the steel. This can be seen in figure 4. The growth of the grain size due to the heat treatment process (holding time) will increasing the grain size to prevent this the holding time must be carefully calculated to avoid grain growth.

![Hardness Vs Holding Time](image)

**Figure 4.** Effect Holding time to Hardness of Specimens

4. **Conclusion**

The investigation of grain growth of powder metallurgy steel after heat treatment showed that holding time increases the grain size where it grows from 3.2 µm to 6.3 µm. This also reduces the hardness of the steel from 261 to 207 HV.

5. **Acknowledgments**

A great appreciation was delivered to the State University of Malang for funding PNBP trough a research contracts no: 20.3.33 / UN32.14.1 / LT / 2019

**References**

[1] Dieter G E, Bacon D, and Wilkes G L 1988 *Mechanical Metallurgy* (Singapore: Mc Graw-Hill Book Co)

[2] Kalpakjian S, Schmid S R, and Musa H 2009 *Manufacturing Engineering and Technology* (Singapore: Prentice Hall)

[3] Javanbakht M, Hadianfard M J, and Salahinejad E 2015 *J. Alloys Compd.* **624** p 17

[4] Peng H et al. 2018 *Mater. Sci. Eng. A* **719** p 21

[5] Ptačinová J, Sedlická V, Hudáková M, Dlouhý I, and Jurči P 2017 *Mater. Sci. Eng. A* **702** p 241

[6] Callister W D Jr, Rethisch D G 2007 *Materials science and engineering: an introduction* (Danver: John Willey and Sons)

[7] Tiamiyu A A, Eskandari M, Sanaye M, Odeshi A G, and Szpunar J A 2016 *Mater. Sci. Eng. A* **673** p 400

[8] Park J J, Hong S M, Park E K, Kim K Y, Lee M K, and Rhee C K 2014 *Mater. Sci. Eng. A* **613** p 217

[9] Erden M A, Gündüz S, Türkmen M, and Karabulut M 2014 *Mater. Sci. Eng. A* **616** p 201

[10] Ateba Betanda Y A, Helbert A L, Brisset F, Mathon M H, Waeckerlé T, and Baudin T, 2014 *Mater. Sci. Eng. A* **614** p 193

[11] Jurči P, Dománková M, Hudáková M, Ptačinová J, Pašák M, and Palček P 2017 *Mater. Charact.* **134** p 398