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Analysis of the Effect of Tempering Temperature on the Formation of Microstructure and Hardness Values in SKD11 Steel

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ABSTRACT: SKD11 steel is a tool steel material. SKD11 steel must have strong and tough mechanical properties. So to improve the quality and ability of SKD11 steel to accept external loads and forces, it is necessary to heat treatment. The heat treatment carried out in this research is hardening and hardening – tempering. The hardening process is carried out by heating SKD11 steel at austenitic temperature of 950 °C and holding time of 30 minutes. Then fast cooling (quenching) with water cooling media. As for the hardening – tempering process with temperature variations of 400 °C, 500 °C, 600 °C and a holding time of 60 minutes. In the as-quenching process the microstructure formed is martensite and residual austenite which cannot be transformed. Increasing the tempering temperature affects the martensite formed into tempered martensite consisting of ferrite and cementite carbide. In addition, with increasing tempering temperature the volume of carbide distribution will decrease and have a smoother shape. As the volume of carbide distribution decreases and the ferrite structure becomes more consistent, the ductility of the steel will increase and the hardness will decrease. The hardness value of SKD11 steel with hardening of 950 °C is 61.5 HRc. While the steel with hardening - tempering at a temperature of 400 °C = 57.3 HRc, 500 °C = 56.3 HRc, and 600 °C = 49,5 HRc. Increasing the tempering temperature will increase the ductility and decrease the hardenability on SKD11.
KEYWORDS: SKD11 steel, tempering temperature, microstructure, mechanical properties

INTRODUCTION

SKD-11 steel is a type of high quality stainless steel which is a tool steel and is widely used in industry because it has high hardness and wear resistance. SKD11 steel material can be increased hardness and ductility through heat treatment. To obtain a better and longer lasting level of hardness, hardening and tempering processes are usually carried out.

The hardening process is by hardening the steel to the austenitizing temperature, then the next process is quenching, and after that the tempering process is carried out to achieve the desired final hardness. The tempering process is carried out so that the steel has good ductility and is not too hard/brittle. So that with the tempering process it is hoped that the steel will have good hardness and good ductility.

Tempering is one of the heat treatment processes after the hardening process. This process aims to restore some of the toughness/toughness that was lost due to the hardening process (Clark, 1962). The reduced ductility of the metal is due to the transformation of martensite resulting from the rapid cooling of the metal. So that tempering can add ductility and toughness to the metal, it is very important to increase the absorption of impact energy and the tempered martensite structure produces good dynamic strength in steel (LI Hong-ying, 2013).

Martensite is a metastable structure. If the martensite structure gets heat treatment (tempering). The carbon in the BCT structure of martensite will come out into carbide and BCT will transform into BCC ferrite.

This study aims to determine the effect of variations in tempering temperature on the microstructure formed and the hardness value of SKD11 steel.

RESEARCH METHODS Research Material

The SKD11 steel material used in the study uses material from PT. Daido Steel Indonesia with the brand name DC11.

Research Stages

The test material is named with the name of each sample A, B, C and D which will be subjected to heat treatment. All specimens went through the hardening stage with a temperature of 950 ^oC and a waiting time of 60 minutes. Then rapid cooling was carried out with water cooling media. Then after the hardening stage was completed for specimen A no tempering treatment was carried out. As for specimen B, tempering will be carried out with a temperature of 400 °C and a waiting time of 60 minutes, after which it will be cooled quickly using air cooling media. Furthermore, for specimen B, tempering will be carried out with a temperature of 500 °C and a waiting time of 60 minutes after that it is quickly cooled using air cooling media. Finally, specimen C will be tempered with a temperature of 600 °C and a waiting time of 60 minutes, after which it will be cooled quickly using aircooled media.

Hardness Test and Microstructure Testing

After the preparation of each specimen was completed heat treatment. The next step is to do hardness testing. Hardness testing is used to determine the hardness value of each specimen. The tools used for hardness testing use Hardness Rockwell Test.

After the hardness test is completed, it is continued with testing the microstructure of each specimen using a metallurgical microscope. Microstructure testing is expected to show the results of differences in the structure of each specimen that has been through the hardening and tempering treatments. So that the results of microstructure testing can be used for the analysis process and determine the mechanical properties of each specimen. In the process of testing the microstructure, an etching liquid is needed. Etching serves to see more clearly the microstructure formed on the specimen. In testing the etching microstructure used is Nital 4%.

RESULT AND DISCUSSION Hardness Testing

Material hardness is the ability or resistance of a material to withstand indentation or deformation loads on the material. The purpose of hardness testing is to measure the resistance level of the material and determine the mechanical properties of the material. Heat treatment of materials generally causes a change in the hardness of the material. In this study the hardness test used the Hardness Rockwell Test. The results of the hardness test for each sample can be seen in the following table.

Table 1. Rockwell Hardness Testing Results (HRc)

Test Object Code	Hardness Test Point			Mark Violence Average
	Point 1	Point 2	Point 3	
A	60.5	63	61	61.5
B	56.5	57.5	58	57,3
C	55.5	57	56.5	56.3
D	49.1	50	49.3	49.5

Information :

Test Object Code

A (*Hardening* 950 °C)

B (*Hardening* 950 °C + *Tempering* 400 °C)

C (*Hardening* 950 °C + *Tempering* 500 °C)

D (Hardening 950 o C + Tempering 600 o C)

Figure 1. Effect of material conditions with hardening and hardening – termpering treatment on the hardness value (HRc)

Then the results of the hardness values of the 3 points are averaged to become the hardness value of the sample. Figure 1 explains that the relationship between the sample treatment and the sample hardness value. In the graph, the steel sample code A with a hardening treatment of 950 °C gets a hardness value of 61.5 HRc. While the steel code sample B with a hardening treatment of 950 °C and continued with a tempering process of 400 °C obtained a hardness value of 57.3 HRc. After that, steel code sample C with a hardening treatment of 950 °C and continued with a tempering process of 500 °C obtained a hardness value of 56.3 HRc. Finally, steel code sample D with a hardening treatment of 950 °C and continued with a tempering process of 600 °C obtained a hardness value of 49.5 HRc. The highest hardness was obtained from sample code A steel with a hardening treatment of 950 °C without a tempering process, namely 61.5 HRc, and the smallest hardness was obtained from sample D steel with a hardening treatment of 950 °C and a tempering process of 600 °C, which was 49.5 HRc. As the tempering temperature increases, the hardness value of the steel will decrease and the ductility of the steel will increase.

Observation of Microstructure

Results of microstructure observations of SKD 11 steel with hardening treatment at 950 o C and holding time of 30 minutes then rapid cooling using water cooling media can be seen in Figure 4.2 The structure contained in the as-quench sample is a matrix in the form of mertensite (M), carbide (C) and retained austenite . The martensitic structure is formed due to the fast cooling rate at the austenite temperature. The rate of cooling (quenching) in steel is very influential on the phase formed. The rapid cooling process does not produce 100% martensite structure but also produces retained austenite. Retained austenite is austenite which does not undergo transformation into martensite upon rapid cooling or we can call it residual austenite. The average remaining austenite during the quenching process ranges from 10% - 30%. The reason for the formation of retained austenite after the quenching process is because during the quenching process the martensite structure phase does not reach Mf (Martensite Finnish) on the CCT (Continuous Cooling Temperature) diagram, p. This can be caused by the low temperature (Martensite finnish) due to the influence of the alloying elements. However, the remaining austenite cannot be seen in the microstructure. SEM and XRD testing is required to determine the amount of austenite remaining in the post-process material. Then the formation of the carbide structure is influenced by the presence of Chrom elements in SKD11 steel. Structure the carbides formed can also be called chromium carbides.

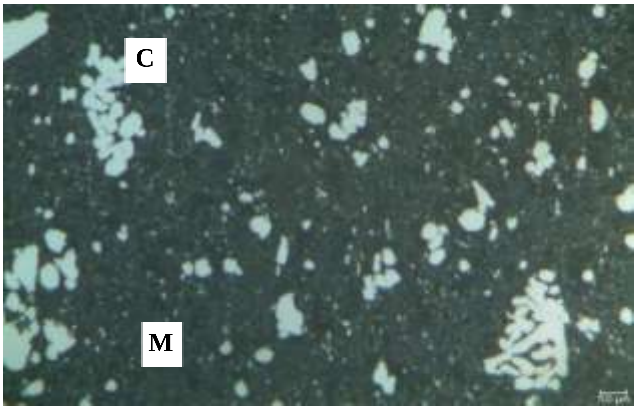

Figure 2. SKD11 microstructure after hardening process with 500X magnification.

Observation of the microstructure of the specimens by hardening treatment with a temperature of 950 °C and holding time of 30 minutes then fast cooling using water cooling medium (quenching). After that, the specimens were tempered at a temperature of 400 °C with a holding time of 60 minutes and followed by a cooling process with air cooling media. Figure 3 Observation results of as- tempered steel 400 °C, the microstructure formed is Martensite Temper (MT), Chrom Carbide (C) and retained austenite . The martensite formed from tempering is called tempered martensite, namely martensite which has changed its microstructure to ferrite and cementite carbide (Fe_3C) . The tempering process on SKD11 steel causes the martensite phase formed from the as-quenching process to transform into ferrite and cementite carbide. Meanwhile, carbides from chromium alloy elements have a smaller shape. Then there is still retained austenite (remaining austenite) which has not been completely transformed.

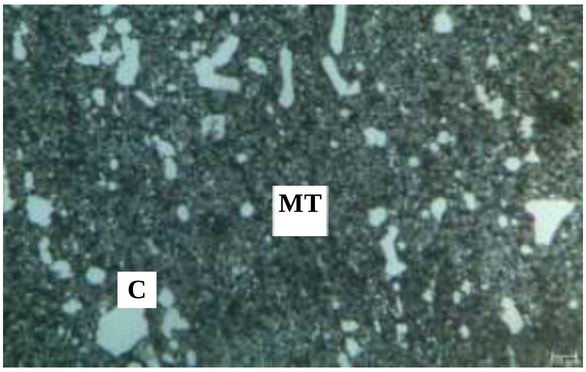

Figure 3. SKD-11 microstructure after 400 °C hardening and tempering process with 500X magnification.

Observation of the microstructure of the specimen with hardening treatment at a temperature of 950 o C and holding time of 30 minutes then fast cooling using water cooling media. After that, the specimen was subjected to a tempering process with a temperature of 500 °C with a holding time of 60 minutes and followed by a cooling process with air cooling media. Figure 4 Observation results of as- tempered steel 500 °C, the microstructure formed is almost the same as the as-tempered condition of 400 °C, namely Martensite Temper (ferrite + carbide cementite (Fe_3C)), the difference is that the distribution of ferrite is more even and the volume of distribution of chromium carbide (C) on the as-tempered condition of 500 °C has a smaller and finer carbide size than the as-tempered condition of 400 °C. This can be seen in the photo of the microstructure with the as- tempered condition of 500 °C. The remaining austenite also decreases in the as-tempered condition of 500 °C. Retained austenite (remaining austenite) will be totally transformed and become pearlite phase at tempering temperature ≥ 520 °C.

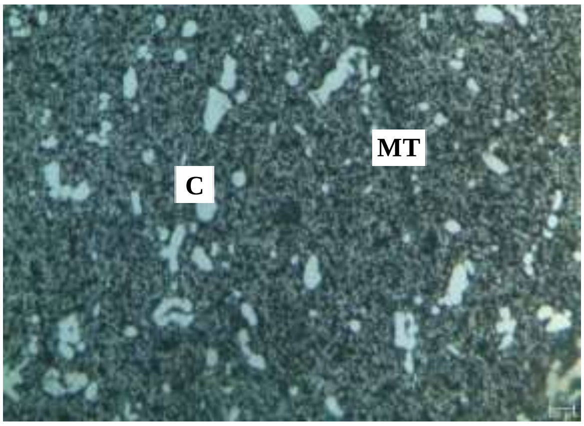

Figure 4. SKD-11 microstructure after 500 °C hardening and tempering process with 500X magnification.

Microstructure of the specimen with hardening treatment at 950 °C and holding time of 30 minutes then fast cooling using water cooling media. After that, the specimen was subjected to a tempering process with a temperature of 600 °C with a holding time of 60 minutes and followed by a cooling process with air cooling media. Figure 5. Observations of as-tempered 600 °C steel material, the microstructure formed is almost the same as that of as-tempered 500 °C, namely Temper Martensite (Ferrite + cementite carbide (Fe_3C), the difference is ferrite which is more stable and The volume of chrom (C) carbide distribution in the astempered condition of 600 °C is more than the volume of carbide distribution in the as-tempered condition of 400 °C and 500 °C. This can be seen in the microstructure photo with the as-tempered condition of 600 °C has carbides with a smaller size than the as-tempered conditions of 400 °C and 500 °C. At a temperature of 600 °C the carbide has a smaller size, more spread, and smoother has a spheroid shape.

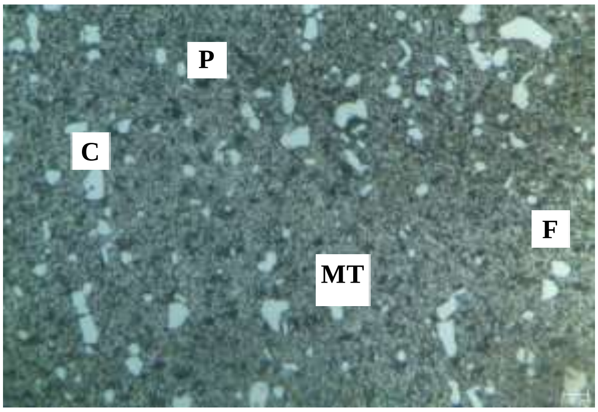

Figure 5. SKD-11 microstructure after hardening and tempering 600 °C with 500X magnification.

The Effect of Tempering Temperature on the Microstructure of SKD11 Steel

This study aims to observe and analyze the effect of different tempering temperatures on the microstructure formed in SKD11 steel. The microstructure obtained from the hardening-tempering treatment was compared to the microstructure obtained from the hardening treatment without tempering.

hardening heat treatment process was carried out at an austenitizing temperature of 950 °C with a holding time of 30 minutes, and water cooling medium. Then for the tempering process carried out at temperatures of 400 °C, 500 °C, and 600 °C with a holding time of 60 minutes.

SKD11 steel in the as-quenched condition has a hardness value of 61.5 HRc and the results of observing the microstructure in samples that were only hardened without tempering are shown in Figure 2. The structures formed are matensite and residual austenite. The rapid cooling process with water resulted in the formation of a hard martensite structure and the transformation of the austenite FCC crystal structure into a martensite BCT crystal structure. Martensite has a crystal structure that is unstable, shaped like a needle, very hard and brittle. The BCT (Body Centered Tetragonal) martensite crystal structure is caused by the rapid cooling process, so carbon does not have time for diffusion transformation. Then the fast cooling process also results in no time for austenite to turn into ferrite. So it can be said that the formation of martensite is the result of austenite transformation which is influenced by the fast cooling rate and carbon content in steel. The strength of the martensite formed depends on the amount of carbon content in the steel material. The higher the carbon content in steel, the harder the martensitic structure will be . The increase in material hardness can also be affected by carbides. The carbide formed in the SKD11 material is influenced by the presence of the Chromium alloy element present in the material. Primary and eutectic carbides are carbide structures formed from a solidification process. Where materials with high chrom content will react with carbon elements and form M_7C_3 compounds, these compounds will occupy empty space (vacancy) in the grain boundary area, so that they can form carbides continuously.

SKD11 steel in as-tempered condition 400 °C get a hardness value of 57.3 HRc. Furthermore, for the as-tempered condition of 500 °C it produces a hardness value of 56.3 HRc. Then the steel samples in the as-tempered condition of 600 °C produced a hardness value of 49.5 HRc.

Then for the results of the microstructure of the steel samples which were hardened and tempered at temperatures of 400 ° C, 500 °C and 600 °C, it can be seen in Figures 3, 4 and 5 that the microstructure formed is a tempered martensite matrix (ferrite and carbide). cementite), then the carbide structure which is influenced by chromium alloying elements in SKD11 steel. In addition, there is also an austenite structure that cannot be decomposed properly during the quenching process or is commonly called residual austenite but is not clearly visible in the microstructure. The tempered martensite microstructure formed from the martensite tempering process is a combination of ferrite and cementite carbide. The tempering process produces a ferrite phase fraction where ferrite has soft and ductile properties. Thus increasing the elasticity of steel. The tempering process also affects the carbon contained in the steel. The martensite tempering process can lead to the deposition of a carbon-rich phase into an epsilon carbide phase. The formation of this phase causes the carbon content in the steel to decrease. The formation of carbide in the tempering process will make steel have good strength.

The results of the tempering process at temperatures of 400 °C, 500 °C and 600 °C with the formation of ferrite and carbide microstructures can affect the mechanical properties of steel. The microstructures formed in the tempering process are ferrite and carbide phases. The higher the tempering temperature, the ferrite phase will increase and the more stable it will be. At a tempering temperature of 600 °C the remaining austenite structure will be fully transformed into pearlite and chromium carbide will be transformed into spheroid carbide. Pearlite has strong and hard properties. Tempering temperature will also affect the carbide formed. The higher the tempering temperature, the more and finer the distribution of carbides from chromium elements. So that the higher the tempering temperature can affect the stability and the number of fractions of the soft ferrite phase offset by the hard pearlite and carbide phases. So that steel has good toughness, strength and ductility.

CONCLUSIONS

Tempering temperature 400 °C, 500 °C ¸ 600 °C The microstructure formed is almost the same, namely tempered martensite consisting of ferrite + cementite carbide, then chromium carbide. Tempering temperature variations can affect the hardness value that is formed on SKD11 Steel. The hardness value of steel with quenching without tempering process is 61.5 HRc. Meanwhile, the hardness value of the material with the addition of 400 °C tempering resulted in a hardness value of 57.3 HRc. Then for a tempering temperature of 500 °C it produces a hardness value of 56.3 HRc. Finally, a steel sample with a tempering temperature of 600 °C produces a hardness value of 49.5 HRc. The higher the tempering temperature, the more and more consistent the distribution of the ferrite structure will be, so that the higher the tempering temperature can affect the hardness value of the material. Steel material becomes more ductile and has good resistance to external forces or loads.

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