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EFFECT OF HEATING TEMPERATURE AND DIE INSERT DRAFT ANGLE ON THE FLOWABILITY OF HOT FORGED SCM435 STEEL

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Abstract

The flowability problem of a closed forging process in the heavy equipment industry is still widely found. This problem may affect the quality of the product. To solve this problem, the effect of heating temperature and die insert draft angle on the characteristic of hot forged SCM435 steel used for undercarriage track roller has been examined. In the experiment, the workpieces were hot forged at a heating temperatures of 1150 °C, 1200 °C, 1250 °C, and die to insert draft angles of 3°, 5°, and 7° to form undercarriage track roller products. The mechanical properties of the specimens taken from the workpieces were characterized through hardness and dimensional changes, whereas the microstructure was characterized using an optical microscope. The results showed that increasing the heating temperature and die insert draft angle resulted in good flowability. The best product with the specified diameter of 191.2 mm and height of 53.6 mm was obtained from the heating temperature of 1250 °C at the die insert draft angle of 7°. This characteristic agreed with the specified forging design for the undercarriage track roller.

Keywords: *Flowability, hot forging, track roller, undercarriage, underfilling*

1. INTRODUCTION

The growth of heavy equipment industries continues to experience ups and downs in line with its use [1]. To keep this heavy equipment industry running, innovation is needed in the production line by continuously improving in the manufacturing process, both in assembly and component processes [2]. Heavy equipment components are generally made through metal forming technology [3]. One of the metal forming processes for this purpose is the hot forging process. Compare to other processes, the advantage of this hot forging is the strength and toughness of the product that can be controlled closely [4]. In this instance, hot forging can be applied to heavy equipment parts that require high strength and toughness.

One of the parts in the heavy equipment is a track roller contained in the undercarriage that serves as a unit weight divider to the track and a track link driver [5]. Track roller is one of the undercarriage components made with the hot forging process, especially through a closed die hot forging [6]. In the process, however, there is still a problem with an underfilling that results in the defective product. The effort is necessary to solve this problem, primarily in avoiding any losses arising from the defective product.

Underfilling is a condition in which the material can not to fill the desired die during the hot forging process. This condition is affected by many factors, such as improper die forging design, incorrect forging methods, less material, and insufficient material heating temperature [4]. In this instance, design is one factor that affects the material's flowability during hot forging. Improving the design, it will also enhance the flow of the material to reduce defective products. In their research, Mane and Patil [7] have made corrections to the die design in the axle beam. This improved design, it has been proven to improve product productivity [8]. Furthermore, the insufficient heating temperature during the hot forging may cause less flow of the material, and thus, the material cannot fill the die properly [9]-[10]. The worst condition could occur because hot forging at this insufficient

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temperature may result in crack initiation and thus, the defective product.

According to the JIS (japanese industrial standards) [11], this steel is considered high-strength steel with wide range of applications such as automobile clutches, shafts, gears, undercarriage, and flywheels parts [12]-[13]. However, this steel has a drawback in which during the hot forging process, it cannot fill the desired die and thus results in the defect after the process due to an underfilling condition [13].

One of the ways expected to overcome the underfilling problem found in SCM435 steel is by optimizing the heating temperature and die insert draft angle design. In this work, the material was hot forged at heating temperature variations of 1150, 1200, 1250 °C and die to insert draft angles of 3°, 5°, and 7° to form undercarriage track roller products. The results are presented and discussed in detail.

2. MATERIALS AND METHODS

The material was cylindrical bar steel with a dimension of 170 mm in diameter and 400 mm in length provided by PT. Komatsu Undercarriage Indonesia.

Tabel 1. Composition (wt.%) of the as-received material

C	Si	Mn	P	S	Ni
0.364	0.318	1.346	0.008	0.012	0.0
Cr	Mo	Cu	Al	B	Fe
0.517	0.116	0.009	0.033	0.002	Rem

The composition of the as-received material was tested using optical spectrometry, with the result given in Table 1.

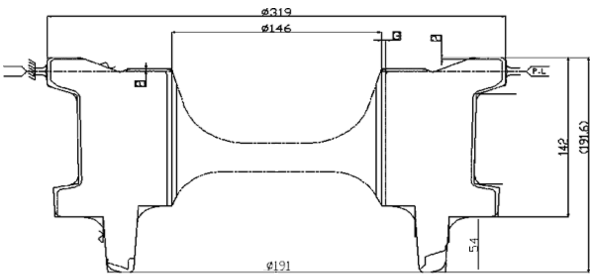

Figure 1. Track roller design. The unit is in millimeter (mm)

The product was designed in the form of a double flange track roller used as an undercarriage component, as shown in Fig. 1. To realize the product, the die was also designed accordingly, which consists of several parts arranged into a single die forging. The part that forms the inside and the end of the track roller is called inner die parts, which are adjustable and made of SKD61 tool steel.

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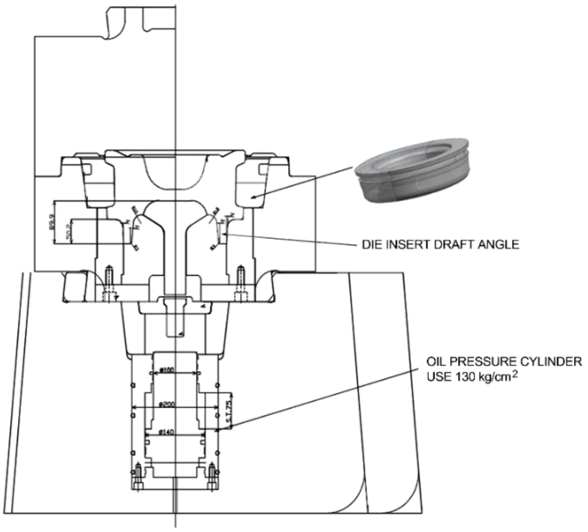
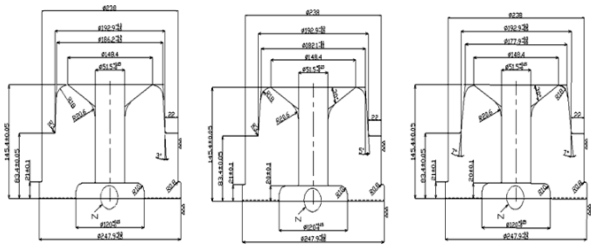


Figure 2. Die structure of the double flange track roller component

In this work, the inner die parts were adjusted to have a variation die insert draft angles of 3, 5 and 7 degrees. The structure and the inner die parts of the double flange track roller components used in this work are given in Figure 2 and Figure 3, respectively.



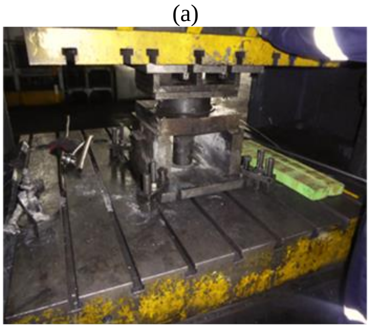
(a) (b) (c)

Figure 3. Die insert draft angle variations (a) 3, (b) 5, and (c) 7 degrees

The work was carried out at PT. Komatsu Undercarriage Indonesia. The experiment began by first installing the die forging on a forging machine and a trimmer jig on a trimming machine. This machine was used to cut the existing flash of the forging products after the process.

After the installation process was completed, the die was preheated to a temperature of 150 °C and left until homogeneous heat was obtained and the piecework materials were ready. The workpieces were then heated at temperature variations of 1150, 1200, and 1250 °C using an induction furnace (Neturen, 1000 kW and 6.6 kHz), which has a very high uniform heating distribution with the help of a conveyor passing through the coil in the induction furnace with a speed of 2.7 mm/s toward the forging machine. Temperature control for each step was carried out using a temperature measuring apparatus before and after the hot forging process. After the hot forging, each workpiece was trimmed, air cooled, and ready for the next treatment. The sequence of this experimental procedure is given in Fig. 4.

(a)



(b)

(c)

(d)

Figure 4. Experimental procedure: (a) die installation of the forging equipment, (b) trimmer jig installation on the trimming machine, (c) the undercarriage product, (d) and the undercarriage after trimming

After the hot forging process, the workpieces were tested for their dimension, hardness, and microstructure. The specimens for the characterization were taken from the bottom part of the workpiece after cross-sectioning it as schematically given in Fig. 5.

The dimension was measured within the original design's closest range, which was 191 mm and 54 mm for diameter and height, respectively. For the mechanical properties, Rockwell hardness testing was performed in according to ASTM-E18-16.

For the microstructural analysis, the specimen was first sand papered up to 1200 grits, then polishing it using diamond paste. After cleaning it with alcohol, the specimen was etched by immersing it in 8 % Nital solution (8 % nitric acid in alcohol) for 10 seconds.

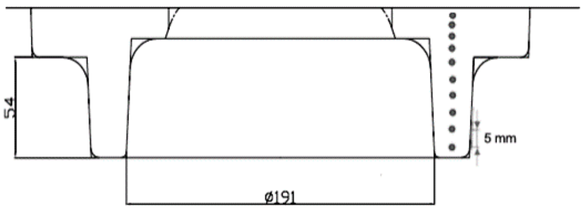


Figure 5. Cross section of the workpiece where the specimens were taken for the characterization purposes

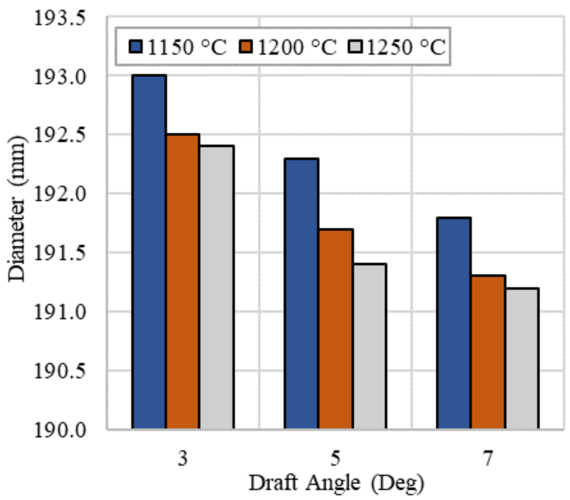
Using an optical microscope (Keyence VHX-5000), the specimen was ready for microstructural characterization. All characterizations was performed at an ambient condition.

3. Result and Discussion

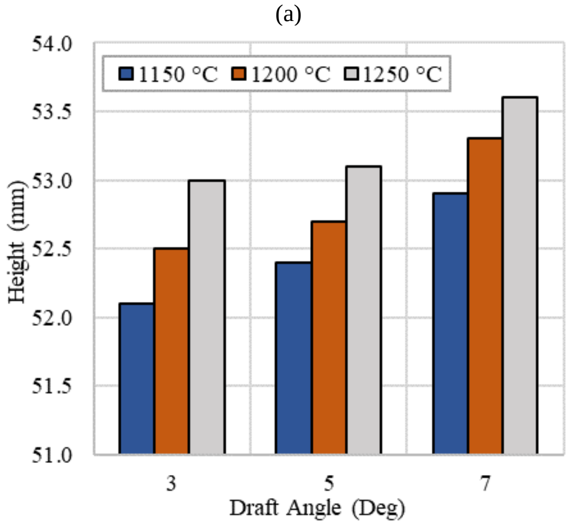
During hot forging, a material undergoes plastic deformation following the shape of the die. To obtain the characteristic of the material's flowability during the hot forging, the dimension of the product was measured in terms of the diameter and height of the track roller product given in the design. In this instance, the flowability of the material is limited to the capability of the material to fill the die during the hot forging process. The results of the dimensional change measurement are given in Fig. 6.

Dimensional change measurement showed that the closest approximated dimensions according to the original product design were the one with a die insert draft angle of 7° and heating temperature of 1250 °C, i.e., 191.2 mm and 53.6 mm for diameter and height, respectively. Other workpieces heated at other heating temperatures using different die insert draft angles experienced off-dimensions in which the diameter and or height of the workpiece could not meet the design specification. At a heating temperature of 1150 °C and a draft angle of 3°, for example, the resulting product has 193.0 mm and 52.1 mm for diameter and height, respectively. It is suspected that the situation could occur because the forging temperature was still relatively low for the material to deform. Moreover, the forging temperature could also somehow decrease during the forging process, which might cause material's flowability to decrease as the temperature decreases.

The die inserts draft angles obviously affected the flowability of the material and, thus, the material's ability to fill the die. As can be seen from the graph, at the same temperature, the 7° draft angle results in more height as compared to that of 5° and 3° draft angles. The draft angle of 7° and heating temperature of 1250 °C results in the highest height at 53.6 mm. This is probably because a large draft angle makes the material easy to flow through the die.



(a)



(b)

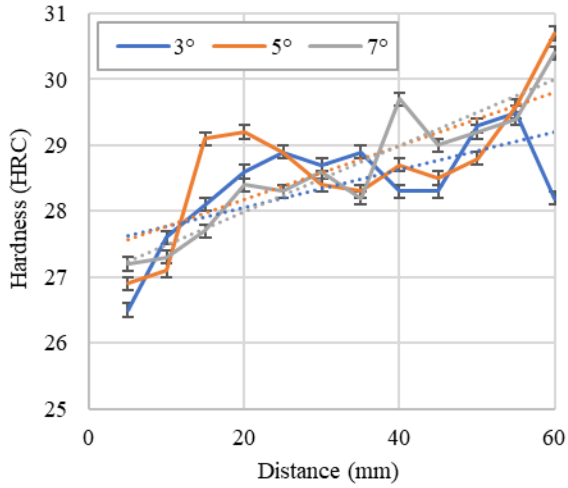
Figure 6. The effect of temperature variations at different die insert draft angles on the dimensional change of the undercarriage track roller products after hot forging (a) height and (b) diameter

During the forging process, plastic deformation may occur in longitudinal and cross sectional directions; however, the degree of change might be differ depending on the flowability and the die design. As seen in Fig. 6, the average value of the diameter is greater than the average height value. In this instance, the deformation is more dominant in the cross-sectional direction, and thus, the change in diameter is larger than that of the longitudinal direction. This corresponds to the state of the forging process, i.e., compression, in which the deformation tends to move freely towards the frictionless (free) direction [14]. From the picture in Fig. 6, it can also be seen that with the increase in temperature and the die insert draft angle, the deformation increases, which means that the material can fill the die well. This is because with the increase of temperature, the more the flow and thus the easier the material to fill the die will be, even at a relatively small load [15].

The hardness testing would be helpful to examine the hardness distribution of the forging products in line with the changes in the forging temperature and die insert draft angle. Hardness distribution from the edge inward at temperature variations of 1150, 1200, and 1250 °C and various die insert draft angles is given in Figs. 7(a), 7(b), and 7(c), respectively. In contrast, the average hardness is given in Fig. 8.

The average hardness of the material after hot forging seems to be affected by the temperature [16] and the draft angle, in, which the higher the temperature and the draft angle, there is a tendency that the hardness also increases. The range of the hardness is about 28-29 HRC, which is statistically insignificant. However, since the hardness of the material before hot forging is about 18.7 HRC, this process profoundly proves that there is an increase of about 54% in hardness after the hot forging. It is expected that the higher the heating temperature, the higher the initial temperature for the air-quenched process. With the carbon content of 0.364 wt.%, as seen in Table 1, it would be understandable that the hardness will also increase with the increase of heating temperature.

At the same temperature, the hardness distribution of the workpiece tends to increase from the edge inward to 1200 °C. This corresponds to the deformation of the material at high temperatures. After experiencing high deformation during the forging, because of high temperature, the recrystallization and, thus, the grain growth at the edge take place faster in comparison to the area inside farther from the edge and therefore make the hardness increase inward. At 1250 °C, even though the difference is insignificant, as mentioned previously, the distribution is almost constant, and the average hardness tends to be relatively lower than that of two other temperatures. This constant hardness distribution is expected due to a more homogeneous temperature distribution.



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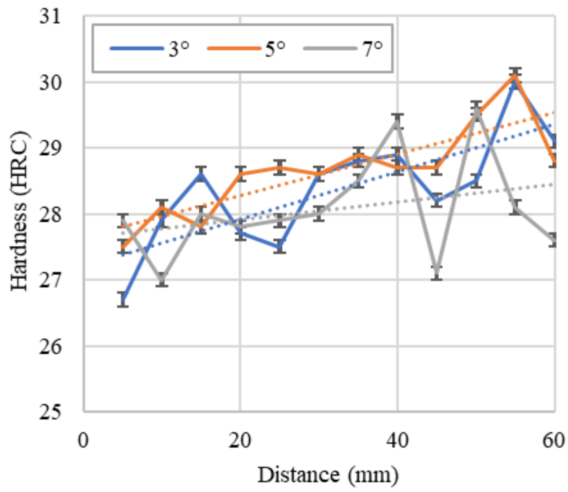

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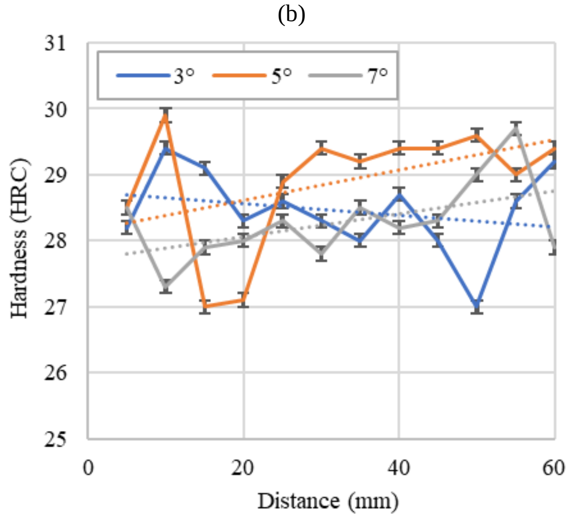


(c)

Figure 7. Hardness distribution from the edge inward at temperature variations (°C); (a) 1150, (b) 1200, (c) 1250 and various die insert draft angles. Error bars are given on each line graph

At this high temperature, it would be much easier for recrystallization and grain growth to take place, and thus, compared to two other temperatures, decrease the average hardness [17].

A microstructural investigation was performed using an optical microscope on the specimen taken from the bottom of the product. The observation was performed at a magnification of 500 x, and the results are given in Fig. 9.

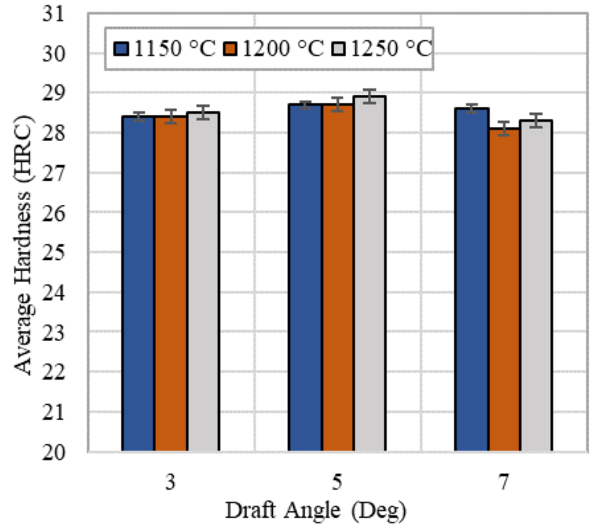


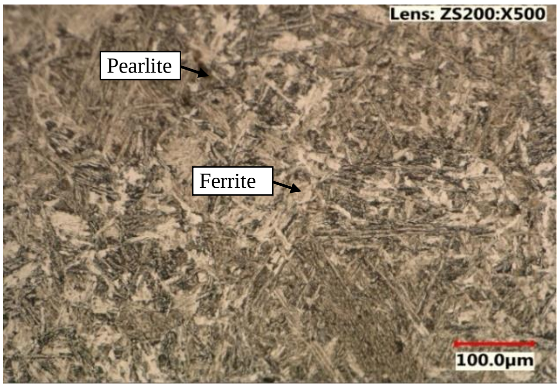
Figure 8. Average hardness from the edge inward at various die insert draft angles and temperature variations. Error bar is given on each bar graph

As can be seen in Fig. 9, the microstructure shows that the edge of the product has a non-homogeneous grain size in which large and small grain sizes are mixed due to a mixture of ferrite and pearlite grains from austenite transformation [18]-[19]. Examination of the microstructures revealed that different heating temperatures result in different phase structures, as can seen in Fig. 9. This microstructure examination supports hardness distribution in which due to more as has been explained previously.

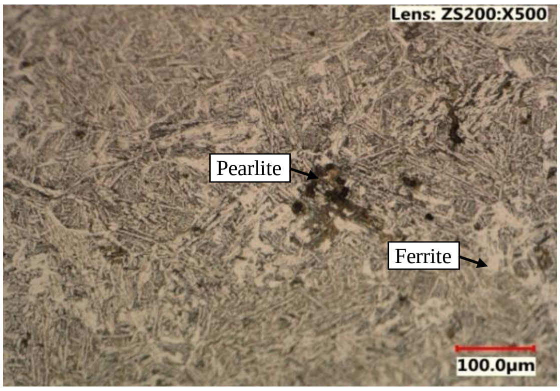
After the hot forging process, some forged products experienced oxidation and decarburization at the tip of surfaces resulting in coarse microstructure [20]. With the increasing temperature, the workpiece becomes susceptible to scale formation and decarburization.

Steel materials with heating temperatures higher than 1150 °C have high sensitivity to decarburization. In this instance, good control is required for the forging process [21]. The depth of the decarburization may affect the material's properties leading to fatigue failure during service if it is not properly handled.

The formation of this scale needs to be considered to determine the appropriate tolerance so as not to reduce the dimensions of ready-made products. This would be primarily true because the uneven surface may lead to an undesired heavy machining process.



(a)



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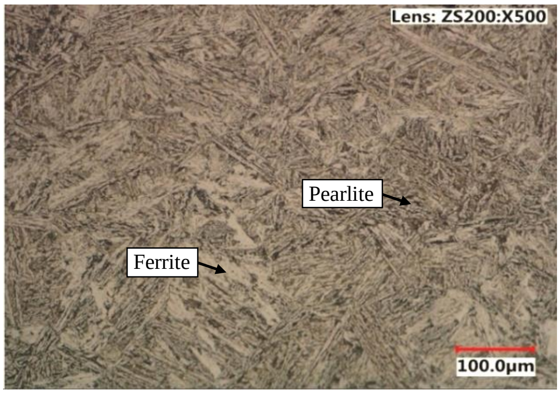

(c)

Figure 9. Microstructure of the workpieces heated (°C) at (a) 1150 with die insert angle of 3°, (b) 1200 with die insert angle of 5°, and (c) 1250 with die insert angle of 7°. Bar scale is 100 µm

4. CONCLUSION

Plastic deformation of the largest after-wrought product occurs at a temperature of 1250 °C and a die draft angle of 7° with a diameter of 191.2 mm and height of 53.6 mm, very close to the desired dimensions for diameter and for height. The distribution of hardness is affected by the temperature and the draft angle in which the higher the temperature and the draft angle, there is tendency for the hardness also increases after the hot forging. The heating temperatures of 1150, 1200, and 1250 °C do not significantly affect the hardness statistically. However, the hot forging process does increase the hardness by about 54% as compared to the original material. The characteristics of the obtained hot-forged material agreed with the specified forging design for the undercarriage track roller. Thus could be further tested for large-scale production.

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