

Analysis of the Powder Forging Processes for Vehicle Timing Belt Pulley by Finite Element Analysis

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Abstract

This paper uses finite element analysis to analyze the changes in mechanical properties and micro structural characteristics of vehicle timing belt pulleys, which is a key component of vehicles engines, made using powder forging processes. The timing belt pulley is an important part that transfers the power generated by the engine to the drive shaft of the valve. The process happens as follows: The powder is inserted into a forging mold, and the product is formed from compression and finally sinter heat-treated in a high-temperature heat treatment furnace. This study aims to perform 3D modeling to analyze the forging process at each stage, then predict the changes in mechanical properties of the product in the subsequent heat treatment process through numerical analysis. The results of analysis will give the load upon the mold punch, product density, temperature distribution and stress and deformation distributions as the result of stroke changes during forging. Next, structural change and temperature distribution according to cooling rate will be found for various individual cross sections following the heat treatment process. The results will allow testing the effectiveness of powder forging process analysis.

Key words: Finite Element Analysis, Forging Processes, Powder Vehicle, Timing Belt Pulley

1 Introduction

The automobile parts industry produces automobile parts using a powder metallurgy for quality consistency, cost savings through mass production and lightweight parts. Recently, powder metallurgy is being applied to the production of engine and transmission parts which are the core drive parts of automobiles¹. The method now accounts for more than 10 percent of all parts. The timing belt pulley is an important part that transfers the power generated by the engine to the drive shaft of the valve. While these parts are made by, casting their shape then mechanically cut or manufactured using the roll forming method, the complex shape of the product leads to prolonged manufacturing time. Accordingly, manufacturing methods using powder metallurgy to forge then sinter heat treat the product are recently being studied^{2,3}. However, as design variables for most of these must be identified through experience and experimentation, this causes high development costs for the production of pilot molds,

etc. Therefore, the need to perform computer process analysis for time and cost savings is urging. Whereas many commercial programs employing finite element analysis have recently been developed and are being used widely to resolve engineering problems, their application in powder forging processes and heat treatment processes is not enough active yet. In the field, empirical research methods that require much time and expense are mainly used^{4,5,6}. In the manufacturing procedure at hand in this study, powder is inserted into a forging mold, then the product is molded by compression, after which it is sinter heat-treated in a high-temperature heat treatment furnace. This study aims to perform 3D modeling to analyze the forging process at each stage, and then predict the changes in mechanical properties of the product in the subsequent heat treatment process through numerical analysis. The results of analysis will give the load upon the mold punch, product density, temperature distribution, and stress and deformation distributions as the result of stroke changes during forging. Next, the changes,

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hardness and temperature distribution, etc., of various post heat-treatment sections according to cooling rate are found. Based on these results, the effectiveness of powder forging process analysis will be verified.

2. Research Method

The material component applied to powder was used with iron of 97%, chromium of 1.5%, and aluminum of 1.5% as the metal powder by mixing. The density of specimen before forging process was assumed to be 20%. The manufacturing method applied in this study was a powder forging process. As the process sequences, it begins with a first compressive forging process using powder raw material by moving upper punch. In the second sequence, specimen is re-compressed by lower punch. DEFORMTM was used to evaluate analytical results of forging processes on the timing belt pulley.

Analyses of these results were performed. Firstly, process design and mold modeling were performed. Applied computer analysis was also performed for forging process and varying process conditions. The mold and punches for powder forging process and 3D modeling were conducted on the timing belt pulley image of 1/4 model as shown by Figure 1. The product shape in this study was the vehicle timing belt pulley at Figure 1(b). Its outer diameter, outer width and inner width were

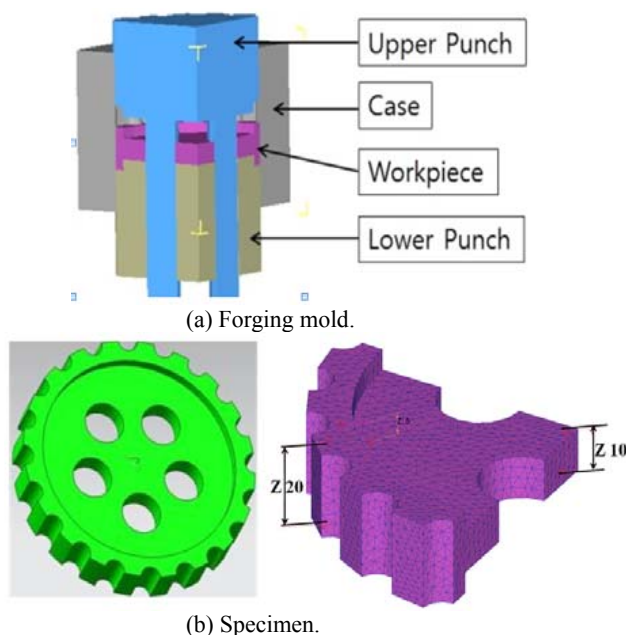


Figure 1. The specimen and 1/4 mesh model.

respectively 120 mm, 15 mm, and 10 mm. The mesh has a tetrahedral structure, with 128,000 elements. In powder forging process, powder metallurgy is filled inside a mold, then, as shown in Figure 2(a), an upper punch is lowered in the primary stage to compress it. Next, the lower punch is raised in the secondary stage to compress the product a second time, completing the product molding. Timing belt pulley heat treatment analysis was performed in a 3-step process as shown in Figure 3. The product was first heated for 2 hours at 1,100°C, and then heated for a second time for 30 minutes in 830°C atmosphere. Lastly, in the third step (b), the product was cooled for 3600 seconds at room temperature (20°C). Each of the TTT (Time Temperature Transformation diagram) curves, phase transformation curves and physical properties of materials were based on the DEFORM code values from empirical DBs. The initial value for the analysis time interval was 0.01 sec, and the maximum temperature change was set not to exceed 2°C.

3. Analysis Results and Discussion

The 3D analysis results of strain flow, deformation, load pressure, and punching load were investigated. The punching load was applied with punch stroke during the forging at first and second process. The maximum forming load of 15.9 ton was applied during the punching stroke.

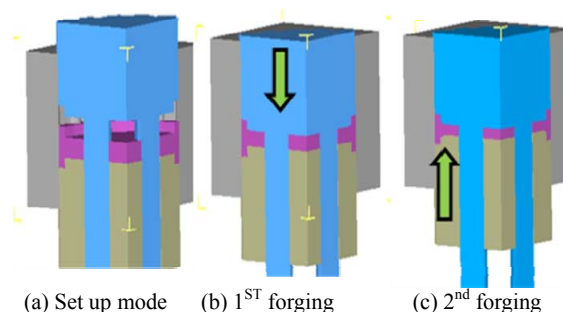


Figure 2. Powder forging process.

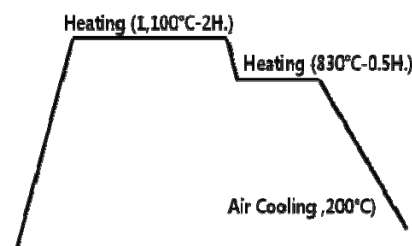


Figure 3. The processes for heat treatment.

Figure 4 shows the load on the punch during compression in the primary and secondary step. First, in the primary step, approximately 5 tons max. load was applied to the upper punch. When the product was compressed additionally using the lower punch in the secondary step, a load of 15.9 tons was applied, demonstrating a load of approximately 3.2 times the primary process is required in the secondary step. It can be seen that load increases sharply in the last compression. Therefore, it was confirmed that a very robust design of the mold was necessary to ensure the lower punch's aptitude to withstand the load. Figure 5 and Table 1 show the change of dimension after the forging process. The outer width before and after

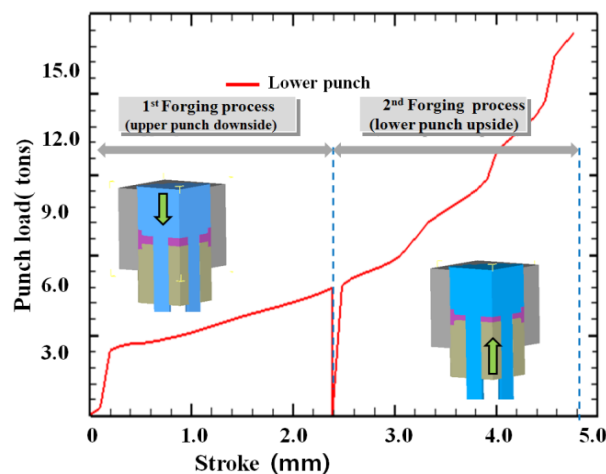


Figure 4. Analysis results on punching load vs. stroke.

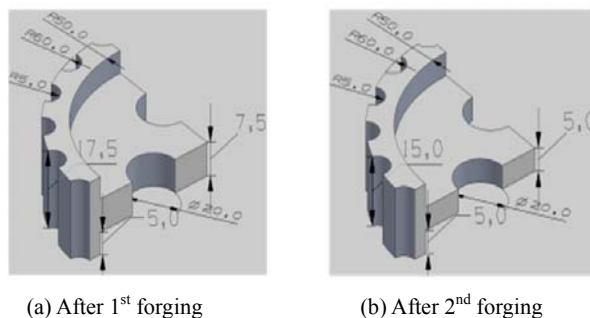


Figure 5. Configurations of deformations after forging.

Table 1. Dimensions of deformation results after forgings

Forging process	Outer width	Inner width
Before forging	15 mm	10 mm
After 1 st forging	17.5 mm	7.5 mm
After 2 nd forging	20 mm	5 mm

forging decreased from 10 mm to 5 mm. On the other hand, the outer width as gear part increased from 10 mm to 20 mm. The analysis results were compared through density distribution as shown by Figure 6. The density of the original material began at 20%; as the charging rate after the first process was 34.2% and the rate after the second process was highly densified at 59.1%, it can be seen that the volume was compressed to approximately 1/3 the original material. In addition, the density was higher toward the center than around the periphery. Therefore, it is predicted that in compression forging, the hardness of the material will be adequate after sufficient heat treatment. Figure 7 shows the results of analysis of the effective stresses acting on the product at the end of the compression. Whereas the maximum stress acting on the product in the first step was 34.3 Mpa, high stress of 149 Mpa was found to be acting on the product after the second step. It is thought that this would have been a cause of improved density. Figure 8 shows the results of analysis for the strain velocity direction and size during forging. It is shown that strain velocity acts from the top down in the first process (a), and in the opposite direction in the second process (Figure 9), with a faster strain velocity in

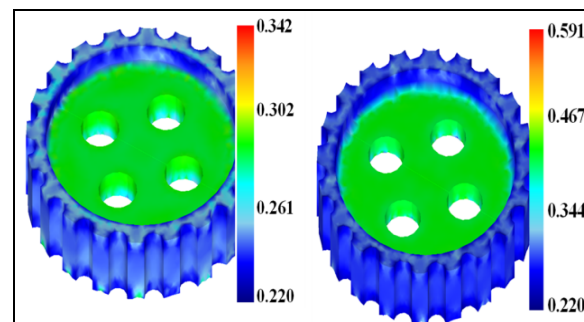


Figure 6. Analysis results on power densities.

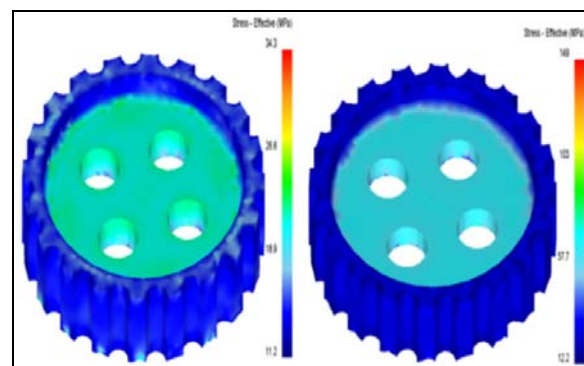
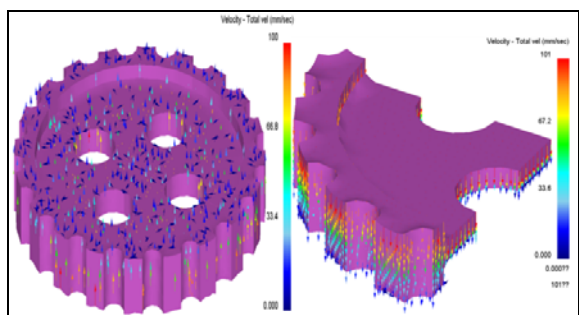
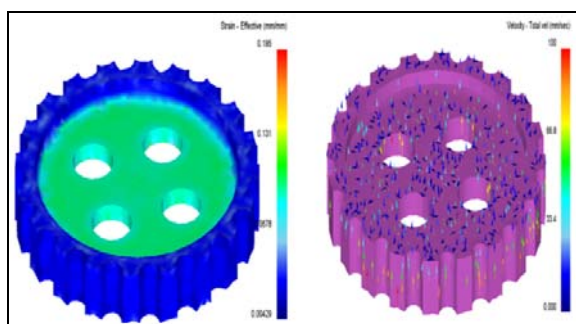


Figure 7. Analysis results.



(a) After 1ST forging (b) After 2nd forging

Figure 8. Analysis results on strain velocity.

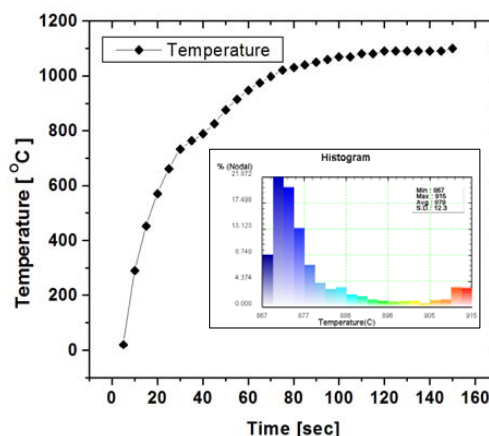


(a) Strain (b) Strain velocity

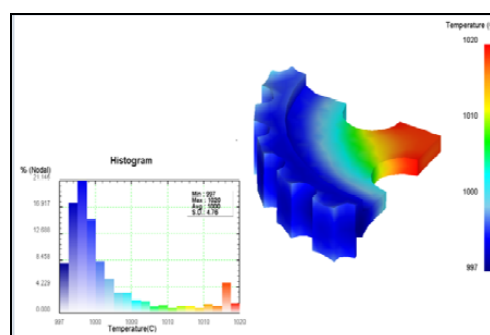
Figure 9. Analysis results on strains at 2nd process.

the parts in contact with the punch. Meanwhile, a 3-step heat treatment process was performed for forging. First, a constant temperature was maintained at 1,100°C, and then the product was heated at 830°C for the second step. In the third step, the product was slowly cooled at room temperature. The temperature increases values according to time for a structure placed in the heating electric furnace are shown in Figure 10. The temperature rises rapidly up to 60 seconds, approaching the furnace temperature of 1100 at 150 seconds. In the temperature distribution, it can be shown that whereas the thinner center section has a high temperature, the tooth form sections have a low temperature. It was noticed that the temperature gap gradually diminished with the passage of time.

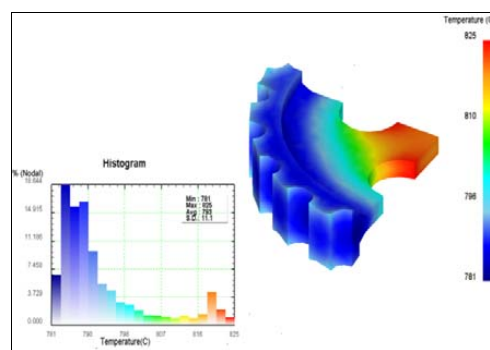
Lastly, the results of analysis for structural change after completion of heat treatment are shown in Figure 11. Comparing the structure when the product is heat-treated than reaches 650 °C during air cooling as shown in Figure 11 with structure (as shown in Figure 12) when the product is cooled to room temperature, whereas the



(a) Temperature vs. cooling time at 50 sec.



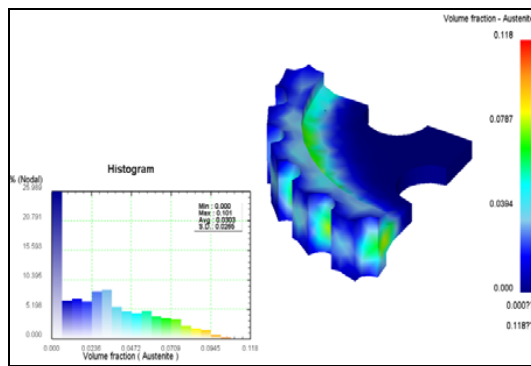
(b) The distribution of cooling temperature (surface temperature of 997°C).



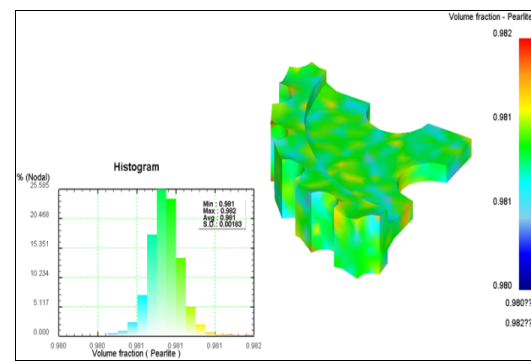
(c) The distribution of cooling temperature (surface temperature of 781°C).

Figure 10. Analysis results of cooling temperature.

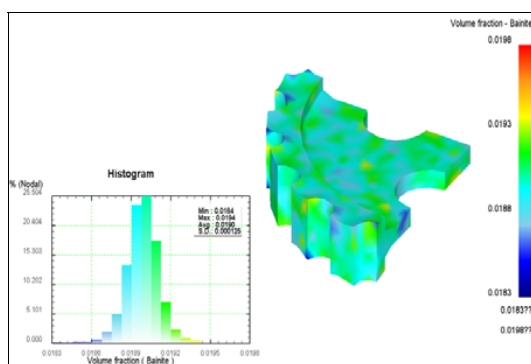
average ratios of austenite, bainite and pearlite structures for (a) were 3.0%, 1.9% and 95%, respectively, in (b), austenite structures disappeared, with bainite at 2% and pearlite, at 98%, accounting for most of the structure. Therefore, it is confirmed that the product has been well annealed into a pearlite structure that is well able to withstand impact, and that heat treatment conditions have been chosen well.



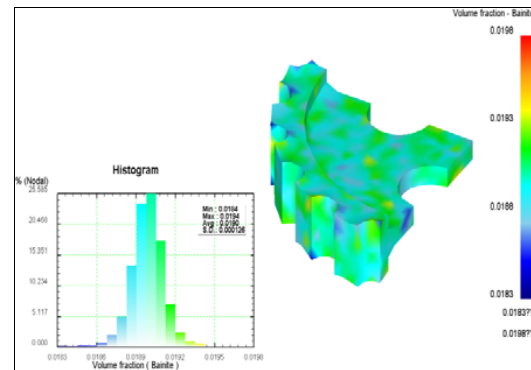
(a) The distribution of austenite.



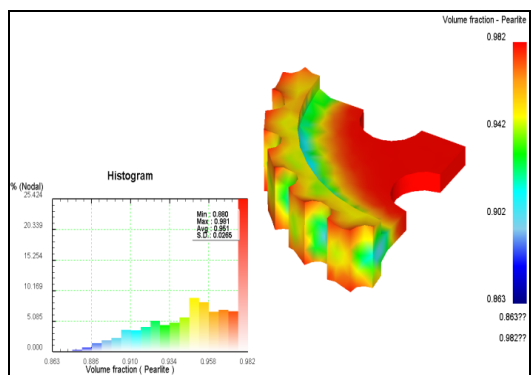
(a) The distribution of pearlite.



(b) The distribution of bainite.



(b) The distribution of pearlite



(c) The distribution of pearlite.

Figure 11. Analysis results on metallographic distribution (at 650°C during oil cooling).

4. Conclusion

This paper uses finite element analysis to analyze the changes in mechanical properties and micro structural characteristics of vehicle timing belt pulleys, a key component of vehicles engines, made using powder forging processes. The following conclusions were reached.

Figure 12. Analysis results on metallographic distribution (after oil cooling).

First, regarding the forging process, a maximum load of approximately 5 tons was applied in the first stage where the upper punch is lowered. When compressing the product additionally in the second forging stage where the lower punch is risen rises, a load 3.2 times larger than the first stage load is required, and the load increases abruptly at this point. Therefore, it was confirmed that robust design of the mold was necessary to ensure the lower punch's aptitude withstand the load.

Next, after forging, heat treatment was performed where the product was heated for 2 hours at 1,100°C then additionally heated for 30 minutes in a 830°C atmosphere and then air cooled. It was shown that as a result, pearlite structure accounted for 98% of the product, with almost no other structure. Therefore, it is confirmed that the product has been well annealed and well able to withstand impact, and that heat treatment conditions have been chosen well. The Powder Forging and heat treatment interpretation attempted in this study enabled the three-dimensional measuring of the structure, temperature change after

the sintering heat treatment and heat treatment though it might be difficult to calculate values quantitatively. It is not required to have any actual forging and heat treatment onsite, since the mechanical properties could be predicted by this analytical approach.

5. References

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