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Aluminum Alloy Piston Fabrication Technology by Super Forging-KIRIU

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Abstract. This research aims to produce pistons a lighter and stronger piston, even in high compression and high engine speed conditions. The piston fabrication process is carried out by super forging using Aluminum as a raw material with a compound choice by Silicon or Magnesium. In addition, the outer layer of the piston is covered by molybdenum with the coating process as nanotechnology to prevent corrosion. Furthermore, the finishing is controlled by the programming system machine named CNC (Computerized Numerical Control). In addition to CNC, the automation system is carried out by the KIRIU machine which is also used in this study. The results of this study show that the use of Al-Si alloy base material has better piston quality and able to withstand high compression or high engine speed. Then, the Al-Si superforging piston compared to the two final automation processes of CNC and KIRIU. The evaluation results have proved that the KIRIU machine provides high accuracy and the actual production increases by 20% compared to CNC.

Keywords **:** Piston, Casting, Superforging, CNC, KIRIU

1. Introduction

A piston is a main moving component contained in a cylinder. In a machine, the function is to transmit force generated from expansion of gas in the cylinder to the crankshaft through a connecting rod. In order to achieve a high-performance engine, power per step at higher speeds is necessary to withstand peak mechanical pressure.

Nowadays, the Al-Mg casting piston is very common to use in many industries which has the main problem of being susceptible to damage on high-compression and high-speed engines. The impact encountered was the high-cost maintenance [1]. If compared with the Al-Si piston forging which is lighter and stronger, it can be used in high-compression and high-speed engines. In this study, the molybdenum coating was examined to used to prevent the corrosion rate [1–4].

In the manufacturing of pistons, to produce cutting results in details has not been able to obtain by only CNC machines [5]. Therefore, to overcome this problem, KIRIU for an automated finishing system was chosen. The automation system by the KIRIU machining engine has a high degree of accuracy and can increase actual production [6]. The Al-Si piston forging is more efficient than the Al-Mg casting piston [7–9]. Efficiency is very important with respect to the costs incurred for maintenance, which will have a large influence on the graph of income budget production [10–13].

The aim of this study is to compare the fabrication technology of Al-alloy piston by casting-CNC and super forging-KIRIU. Through the experiment of the ideal piston speed, compression ratio, piston strength due to the influence of heat, and the volume of wear resistance are determined based on the experimental procedure. The difference results of piston finishing by both automation cutting systems are described in detail in this paper.

2. Experimental Procedure

The manufacturing of piston by casting process is started with foundry. Foundry is located on ingots of heated aluminum in the furnace. The molten aluminum is poured in a hydraulic mold then scooped up with a ladle from a crucible then allowed to cool. The process continued by dehorning, hardening and machining, in which the pistons are dehorned by a vertical milling machine, then hardened [6]. Furthermore, by a lathe machine, the rough edges are cut and the smooth profiles are obtained by means of a turning operation. In the casting process of piston, the CNC machining is used. CNC is the computer program to cut the ring grooves and create an accurate bore diameter by finishing the crown and making oil slots and pin bore. In addition, the grinding process is carried out as a final inspection to complete the size worked on the piston in the final stage.

The forging process begins from the solid aluminium rod type 2618. The slug can be obtained by a saw after cutting the rod into smaller pieces after heated up to 150^{o}C to 200^{o}C. The punch is purposed to heat up to 426^{o}C and applies 2000 tons of pressure onto the slug, as shown in the Fig. 1. The wrist pinhole and oil control holes are large holes which obtained by drilling through both sides of the piston. The three ring grooves are created by a lathe machine. In the forging process, the milling machines are able to shave up to a couple of centimeters off of each side of the piston where the large holes are drilled for the wrist pin insertion. This is to reduce the overall weight of the piston, the step closer to its final form. As the type of press technique, super-forging pistons are forged using a backward extrusion. Backward extrusion is the process where the material from the slug flows back and around the descending punch become cup shape.

Next, the grinding process is carried out to give the crown the shape required according to the design. Then the last process is machining by KIRIU techno automation system which has high accuracy and increases actual production as the job finishes. KIRIU machine has higher precision compared with CNC. Detail parts up to millimicrons size are able to be shaved and increase the production to 20%. Steps to produce a part by KIRIU machine is start from reading drawing, programming, inputing program, and finalized with machining process. By input a programming language, the parameters determine the coordinates of the prefix and adjust the movement through coding in accordance with the KIRIU machine. Coordinate settings are the most important thing in this method. Import data from the part design has done by CAM (Computer Aided Manufacturing) program, continue with data import to the CAM program connected to the KIRIU machine. The final step in this process is applying the program to the every part which readed by KIRIU's machine, then continues to realize the raw material with the machining process. Figure 2 shows the KIRIU machine.

Figure 1. Slugs after cutting.

Figure 2. KIRIU Machine setup.

3. Results and Discussion

Piston speed is the relative speed of the piston against the cylinder wall, which if it exceeds the threshold. In order to prevent the damage in the engine, the amount of piston speed limitation must be considered. Therefore, the piston speed limit is adjusted to the type of engine and the purpose of its use. When the rotational engine speed reaches 15000 rpm, the other subsystem percentages are also gain such as crankshaft of 25.1%, the transmission of 7.9 %, pumps of 11.4 %, crankcase pumping of 8.5 %, pistons of 33.9 % and valve trains of 13.2 %. The ideal piston speed and friction loss is shown in the Table 1 and Figure 3.

Table 1. Typical Mean Piston Speed.

Engine Type	v_{mps} *@max power*
Small industrial engine	7 m/s
Marine & generator	8.5 m/s
Train & truck	11 m/s
Automobile (low speed)	14 m/s
Automobile (typical)	16 m/s
Automobile (hi-performance)	18 m/s
Racing (endurance)	22 m/s
Racing (short race)	25 m/s
Drag racing	30 m/s

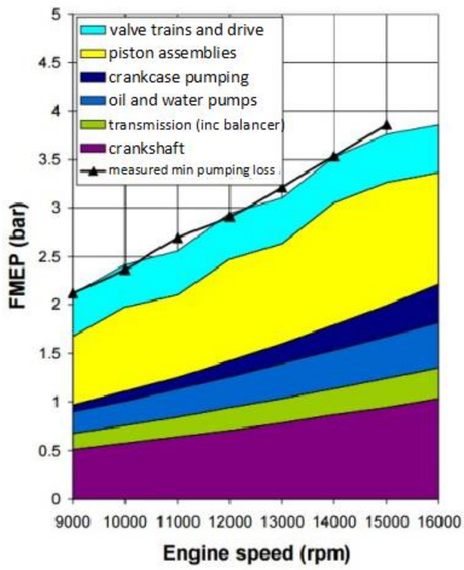

Figure 3. Friction loss of the piston [14].

The ideal piston speed can be calculated by the following equation:

$$\frac{2 \times \boldsymbol{stroke} \times \boldsymbol{rpm}}{60} \tag{1}$$

where 2 is the up and down motion of the piston when the engine rotates once a full rotation, stroke is the step of the piston (m), and rpm is the safe limit of the engine speed.

One of the causes of power loss is the piston friction and the ring with the cylinder (piston assembly), as the first thing that must be considered. This loss is caused by friction that occurs, which is affected by the amount of combustion chamber pressure and piston speed. The sudden increase in piston speed can increase the coefficient of friction between the ring and piston with the cylinder wall simultaneously, as shown in Figure 4.

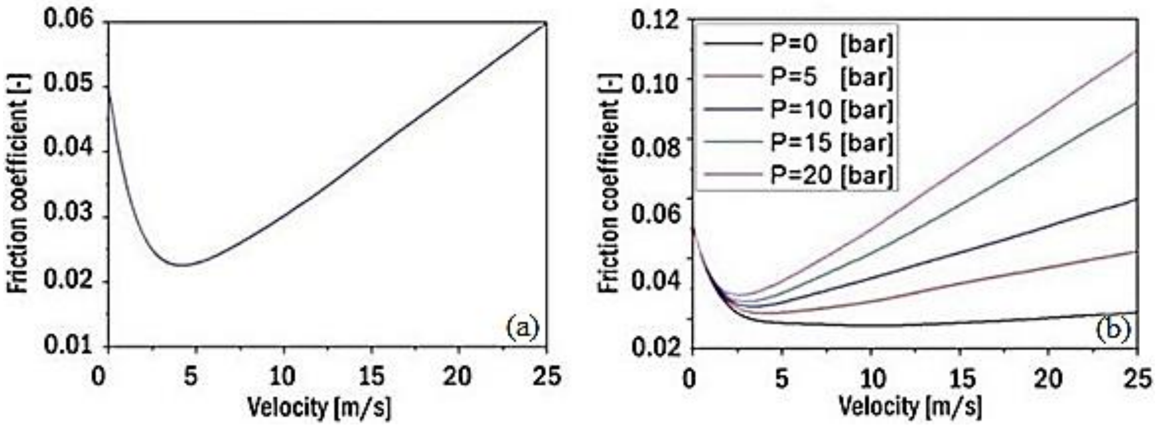

Figure 4. Coefficient of friction between the piston (a) and ring (b) with the cylinder wall.

Figure 5 shows the graph of piston-cylinder power loss on the velocity. The graph explains that the increase in combustion chamber pressure will also increase the pressure of the piston ring to the cylinder wall. Therefore, the coefficient of friction is increasing. As a result of the friction, the engine has a power loss, then it affects the engine room which will gain the temperature and become hot.

If the piston heat continues to increase with increasing piston speed (comparable to the engine speed/rpm), the overheating will occur. Furthermore, this condition to be unable cooled by oil, wind (engine fins) or even a radiator. The effect happens are as follows: the piston ring will expand, the gap with the cylinder wall will be narrower, the coefficient of friction rises and the piston heat is higher followed increased cylinder heat.

In the several engine cycles condition, the piston ring expands in such a way that the distance gap with the cylinder wall is 0, which means very tight and deformed. The piston is stuck and the piston handlebar is broken. If the fracture strikes the cylinder, the cylinder will lose or break. This worst possibility is the objective of the piston manufacturer, avoiding this condition is by giving a limiter at its rpm.

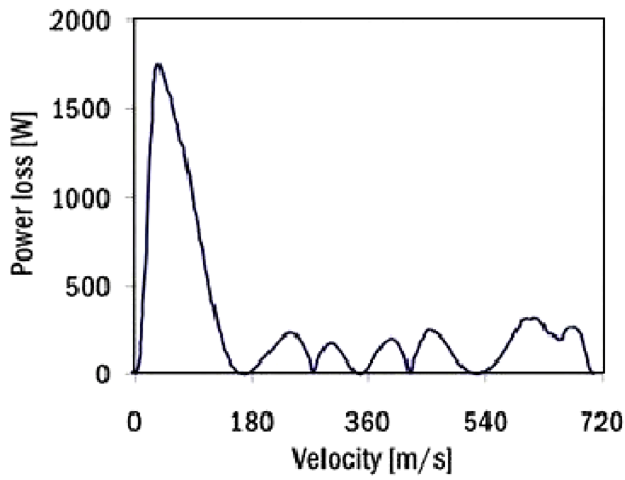

Figure 5. Graph of piston-cylinder power loss.

In addition, it increases the combustion and the piston ring pressures to the cylinder wall, so that the coefficient of friction increase is another thing to note too. As a result of the work of this machine is that it can suffer losses. Therefore, because of the loss of power produced, it can turn hot. Fig. 6 shows the graph of the relationship between piston temperature and engine speed.

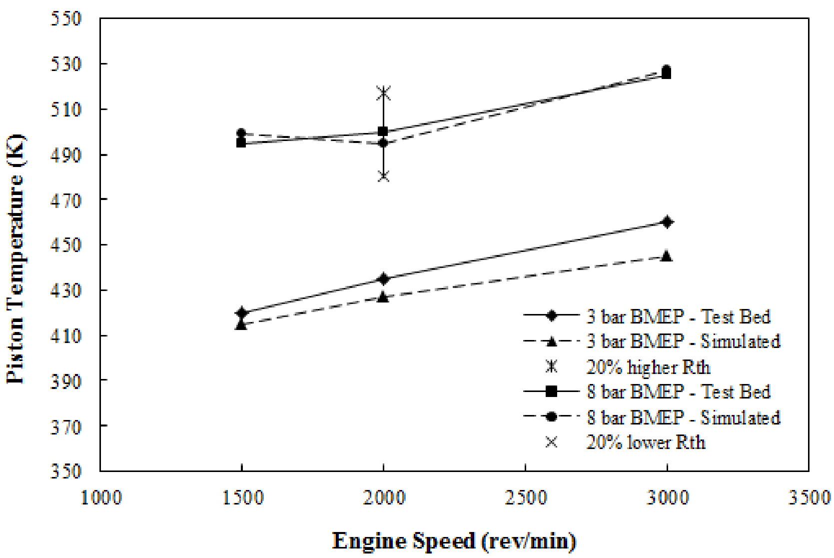

Figure 6. Graph of piston temperature and engine speed.

Besides the coefficient of friction, temperature and engine speed, the compression ratio should also be considered. The following equation is to obtain the compression ratio:

$$\boldsymbol{CR = \frac{V_1}{V_2} + 1} \tag{2}$$

where *CR* is the compression ratio, V_1 is the engine capacity or volume (cc) and V_2 is the combustion chamber volume (burette – the volume of the spark plug hole). Figure 7 shows the illustration of the combustion chamber with schematic changing of compression ratio. The physical differences between casting and super forging piston are shown in Figures 8 and 9, respectively.

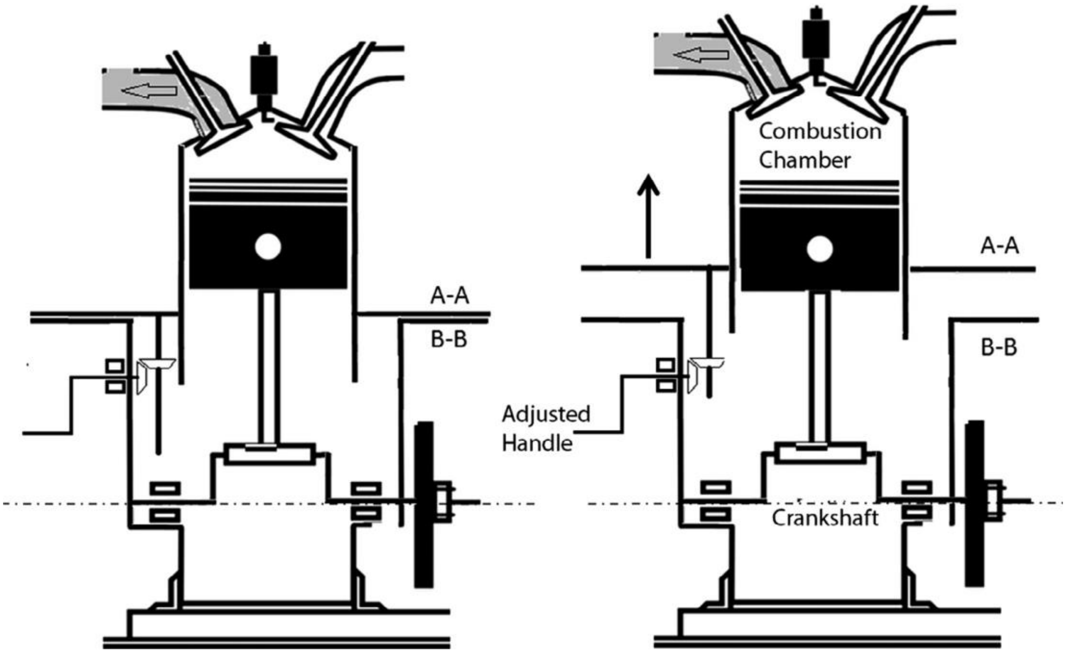

Figure 7. Illustration of a combustion chamber with schematic changing of compression ratio [15].

Figure 8. Casting Piston. **Figure 9.** Superforging Piston.

The piston manufacturing process with the casting method is usually used for low engine speed (RPM) and pistons at affordable prices are easily obtained. This type of piston has poor heat resistance which can be realized. In addition, the physical shape of this type of piston is also thick and heavy. Therefore, this type of piston can increase the compression rate. To overcome this problem, a piston with an advanced manufacturing process was developed. The manufacturing process is through the more expensive super forging method, it is mostly used for high engine speed (RPM). Therefore, through the physical form of a lightweight piston, the compression level can be increased perfectly. By this method, the production successfully increases by 20%. Furthermore, this piston is not easy to expand on the cylinder wall of the combustion chamber. Table 2 and 3 show, the advantages and disadvantages of both manufacturing processes of casting - super forging pistons and the difference of the automation system by KIRIU compared to CNC are as follows.

Table 2. Comparison of casting and forging process.

Advantages		**Disadvantages**	
Casting	Forging	Casting	Forging
• Affordable price Rp. 100.000,- • Generally used for low speed	• Mostly used for high speed or high-speed engines • Resistance of heating higher compared to the casting process • Increases the compression rate • Lightweight 79.6 gr	• Rejecting (metallurgy's environmental effects) • Easy to expand on cylinder wall • Bad heat resistance • Thick and heavy 100.7 gr • Can't increase the compression rate	• Expensive Rp. 450.000,- • Tool path for processing is easy to break • Actual production is not maximum because the manufacturing process is quite complicated and requires a long time

Table 3. The difference of finishing the automation system by KIRIU compared to CNC machining.

KIRIU	**CNC**
• Only a few people are able to operate the KIRIU machine program in each company.	• Many people are able to operate the CNC machine with basic training and skills.
• Higher accuracy than CNC, able to shave a very detailed part into μm.	• Less accuracy compared to KIRIU.
• Able to increase an actual production by 20% with a constant production.	• Production of piston cannot exceed the KIRIU. The number of pistons produced is less than the KIRIU machining.

4. Conclusion

The manufacturing piston has been successfully produced by Si-Mg based Al. The quality of piston in which raw material made by Al-Si is higher compared with Al-Mg alloy. The durability of the piston is increased with super forging and lightweight piston can be obtained. By KIRIU, high accuracy piston can be achieved better than the CNC machining process. Furthermore, by the KIRIU machining process, a more detailed part up to millimicron size can be shaved and the production increases by 20%.

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