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A Study on Friction Characteristics of Multiple Groove Pulleys with Anodizing Coated Aluminum

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Abstract

Considering the mechanism of the pulley, to prevent slipping from the belt, analysis of friction coefficient characteristic is important. Aluminum material is used in weight reduction. Uncoated aluminum materials have low friction coefficient characteristics between V-belt. It is needed to analyze mutual friction coefficient characteristics between coated aluminum material and V-belt.

This is an experimental study on friction characteristics of multiple groove pulleys with anodized surface aluminum. I performed correlating friction test between a belt made of synthetic rubber and anodizing coated pulley made of aluminum 6000 series. A pin-on-disc friction test was performed to observe changes in friction coefficient and equivalent friction coefficient of the Multiple Groove pulley during rotational velocity change. Based on the result, frictional characteristics of coated and non-coated aluminum pulley were analyzed. The results were compared to that of the previously studied non-coated aluminum product and made a correlated comparison analysis.

The friction coefficient of coated aluminum increases steeply at the beginning and maintained equivalent friction coefficient of around 0.66 in a stable manner from the beginning of acceleration, and also during deceleration till reaching around 40rpm. This indicates that the coated aluminum will not slip in acceleration or deceleration and it is a similar tendency to steel. According to the friction test, we can say coated aluminum is suitable for manufacturing pulley because it shows a similar frictional tendency to steel. However, raw aluminum is inappropriate for pulley manufacture since it is very slippery compared to steel.

The coated aluminum is suitable for manufacturing pulley because it will not slip in acceleration or deceleration and it shows a similar frictional tendency to steel. The pulley made of anodizing coated aluminum can be used to reduce the weight of the power transmission system in comparison to steel and increase the power transmission efficiency compared to raw aluminum.

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1. Introduction

The pulley is the most frequently used machine element of the power transmission device. Because of its continuous rotational movement, it has a high inertial force. A pulley is usually composed of multiple interconnected V-belts, and these belts transmit power from the motor or the main driving axle in various types of machinery. Since the V-belt pulley is most of the time made of steel, which makes it very heavy, there are many studies to make the mechanical element lighter[1]. For weight reduction, aluminum alloy is often used, and the friction coefficient is considered to be an important measure[2]. Research trends in the friction and abrasion of machinery components are as follows. Lee[3] conducted an experiment that monitors the sliding surface of the machine element and give feedback of friction condition. Choi[4] studied the relationship between the friction coefficient of inclined element and destruction. In another study, Choi[5] investigated friction and abrasion characteristics of nitriding coated material elements. Meanwhile, Nam et al.[6] verified a theoretical equation on the relationship between friction coefficient and noise. Kim[7] researched on friction coefficient and braking force of wearing plate in friction clutch of vehicle element. Bergseth, E.[8] observed the frictional characteristics of wheel-rail. Thus, there is a lack of study on the friction of the power transmission device. Though, Van Berkel et al.[9] studied high hardness materials as a transmission pulley material. Considering the mechanism of the pulley, to prevent slipping from the belt, analysis of friction coefficient characteristic is important. But frictional study between aluminum material, which is used in weight reduction, and rubber belt is insufficient. Recently, Kim[7] conducted research on friction coefficient experiment using pulley made of aluminum by roll-forming technique. However, slipping occurred because of a low friction coefficient. We identified the need for a technique that reduces abrasion without damaging the friction coefficient of the frictional surface. Therefore, in this study, anodizing surface treatment, which is known to be effective to aluminum, was performed on aluminum and its effect was observed. Anodizing coating method makes electrochemically oxidized layers on the metal anode and cathode[10]. When electricity is flown between metal bars within the electrolyte, oxygen is produced on both anode and cathode. The oxygen oxidizes the surface of metal electrodes forming oxidized aluminum(Al_2O_3) layer, leads to an increase in hardness of the metal surface[11]. This process is known to improve normal anticorrosive, wear resistance, colour fixation, dyeing and insulation.

In this study, the results were performed correlating friction test between belt made of synthetic rubber and anodizing coated pulley made of aluminum 6000 series. In addition, we compared the results to that of the previously studied non-coated aluminum product and made a correlated comparison analysis. We performed a pin-on-disk friction test to observe changes in friction coefficient and equivalent friction coefficient of the Multiple Groove pulley during rotational velocity change. Based on the result, we compared and analyzed the frictional characteristics of coated and non-coated aluminum pulley.

2. Materials and Methods

2.1. Test Piece and Pulley

The material was used aluminum 6000 series to manufacture the pulley. As in Figure 1, test pieces were collected and tested for hardness and tensile. Yield strength was 130MPa, hardness HV 87, and elastic modulus 70.3GPa, which qualifies for use in manufacturing pulley. Table 1 shows the details.

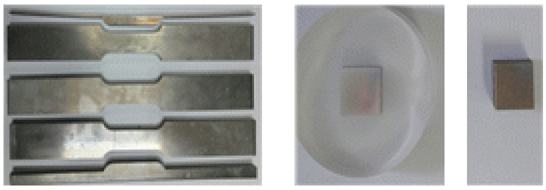

Figure 1. Test specimen for mechanical properties.

Table 1: Test results for mechanical properties.

Spec.	Material property
1. Material	- Aluminum 6000 series - Steel: ASTM A1008-C
2. Tensile Strength, Ultimate	193 MPa
3. Tensile Strength, Yield	130 MPa
4. Elongation at Break	25 %
5. Hardness, Vickers	87
6. Modulus of Elasticity	70.3 GPa

Pulley is made of aluminum material via roll-forming technique in plastic working. The surface was cut using CNC lathe to improve the roughness of the surface. The final piece made by aluminum

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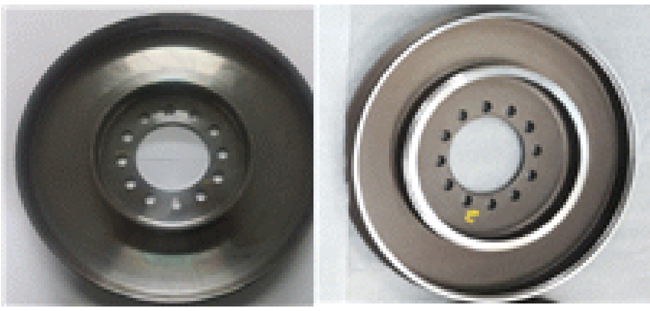
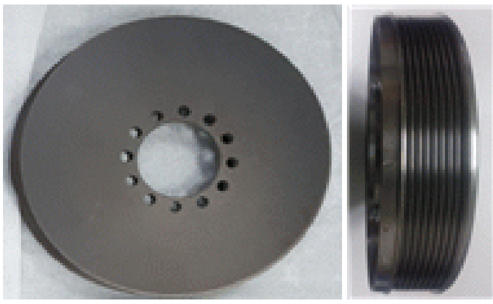
is in Figure 2 (a). The anodizing surface heat-treated version is in Figure 2 (b). In Figure 2 (c), the pulley takes the form of 8 V-belt pulley system that is currently widely used in vehicle and other mechanical power transmissions.



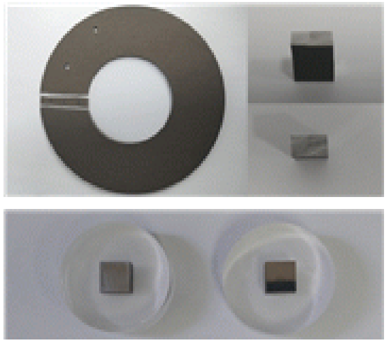
(a) uncoated Aluminum pulley (b) coated Aluminum pulley



(c) coated Aluminum multi V-pulley

Figure 2. Aluminum multi V-pulley

Meanwhile, we checked for vapour deposition of the coating of the coated test piece with SEM, after cutting with cutting pliers. The aluminum material that was left over from the tensile test was cut with wire cut in the proper size and mounted on SEM as in Figure 3. Then the surface of the test piece was ground by polishing, etched with Keller etching reagent that is normally used for aluminum etching, then SEM image was taken and EDS analysis was performed as in Figure 3. The test piece of the belt material is also in Figure 4.



(a) cutting and mounting materials of aluminum

(b) polishing

(c) etching (corrosion)

Figure 3. Specimens for coating deposition analysis

Figure 4. Test piece for Multiple V belt

2.2. Device Configuration and Experiment Method

The test was performed pin-on-disk test[4], a widely used friction test as shown in Figure 5. The bottom of the aluminum pulley is connected to the disc, and the belt test piece is fixed on the pin. The friction coefficient was measured while rotating the disc.

Figure 6 shows the device configuration for the test. The system uses weight as a load and the experiment was conducted as follows. We changed the load condition by varying the weights. The rotation was controlled with step motor (DC motor) connected to PC, and induced friction between rotating metal disk and belt test piece.

Table 2: Data of the pin and disk

Spec.	Pin	Disk
Dimension[m]	0.00215	0.14
Length[m]	0.02	0.005
Width[m]	8e-4	0.6
Material	Steel	Aluminum

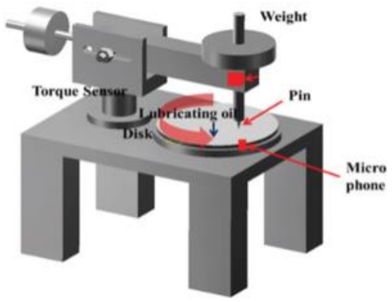


Figure 5. Pin-on-disk system

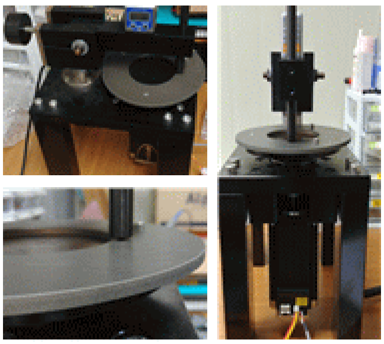


Figure 6. Friction test device

Frictional force data measured by torque sensor was converted electrical signal to physical signal through DAQ. When the measured torque is written in T, frictional force in f can be expressed as equation (1).

$$f = \frac{T}{0.189} \quad (1)$$

Where 0.189m is the distance between the pin and the torque sensor. In the experiment, friction coefficient μ is obtained with equation (2).

$$\mu = \frac{f}{N} = \frac{T}{9.8 \times 0.189} \quad (2)$$

$N = 9.8$N is the normal force of weight 1kgf. The signal was measured as in Figure 6, each directional vibration was measured by 3-axis accelerometer that is attached to the body, and the vibration in the direction of the friction was measured by 1-axis accelerometer that is attached near the pin. The noise made by friction was recorded by installing a microphone near the source of the noise. The test was conducted under 50% humidity, 24℃. The rotational velocity increased 4rpm/sec, and after 1 minute it reached the maximum speed of 240rpm. Then the rotational velocity decreased for 1 minute, and the system stopped in a total of 2 minutes.

3. Results and Discussion

3.1. Coating Experiment

To analyze the composition and vapour-deposition of the coating, SEM imaging and EDS analysis were performed on aluminum material. We used SEM named MIRA LMH from TESCAN which has a resolution of 1nm at 30kV and magnification ranging X12~X1,000,000.

SEM imaging of the coated surface is in Figure 7. The thickness of the coating varies from minimum 28.66μm to maximum 34.70μm. The boundary between the aluminum and the coating was very clear. Coated surface was overall smooth, but in some parts, grooves were found. Normally, the coating of a rotational body thicker than 25μm is considered abrasion-resistant. Since the range of test measurements is above the normal value, it is expected to be safe from abrasion.

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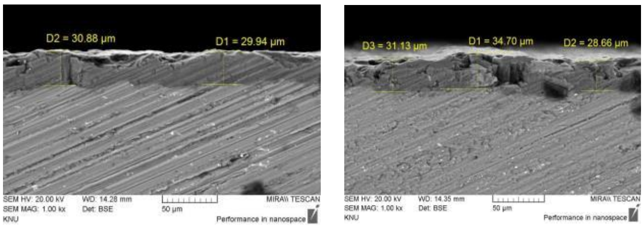
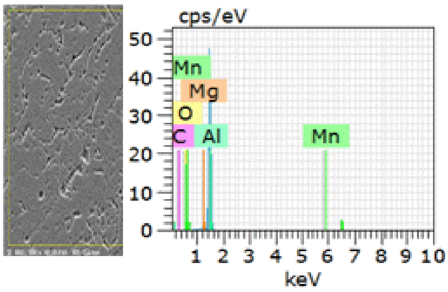


Figure 7. Coasting deposition analysis by SEM

To identify the distribution of the component, we did EDS analysis and the results are shown in Figure 8.

Imaging of all dried materials was possible. When a chemical element from Be to U was above the detection limits (>0.5wt%), the element was detected in the form of a single element. We detected 86.86 [wt.%] aluminum as a major component and 3.93 [wt.%] magnesium.



Spectrum: 1

Element	Series	norm. C [wt.%]	Atom. C [at.%]	Error (3 Sigma) [wt.%]
Carbon	K-series	6.47	13.24	6.44
Oxygen	K-series	2.28	3.50	2.19
Magnesium	K-series	3.93	3.98	0.77
Aluminium	K-series	86.86	79.08	12.91
Manganese	K-series	0.46	0.21	0.16
Total:		100.00	100.00	

Figure 8. EDS analysis result

3.2. Friction Coefficient Experiment

The pin-on-disk friction test was performed with device configuration as in Figure 6. Friction test was performed while the rev count changed and the result is as follows.

The data from the friction test was put into graphs and each experimental group was named raw aluminum and coating aluminum. Data of raw(non-coated) aluminum was taken from the published article[5].

In Figure 9, the friction coefficient of raw aluminum increases and decreases gradually. Next in Figure 10, the friction coefficient of coated aluminum increases steeply at the beginning and maintains an almost constant value over the entire interval from the beginning of acceleration to around 40rpm when decelerating, which is a similar tendency to steel. Also, values on the graph are showing deviation. These phenomena are explained to be caused by chattering between the material and the rubber. According to the friction test, we can say coated aluminum is suitable for manufacturing pulley because it shows a similar frictional tendency to steel. However, raw aluminum is inappropriate for pulley manufacture since it is very slippery compared to steel.

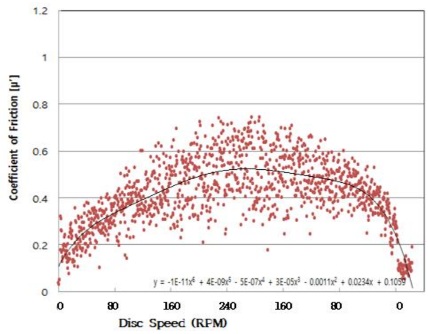


Figure 9. Friction velocity vs. the coefficient of friction (raw aluminum)

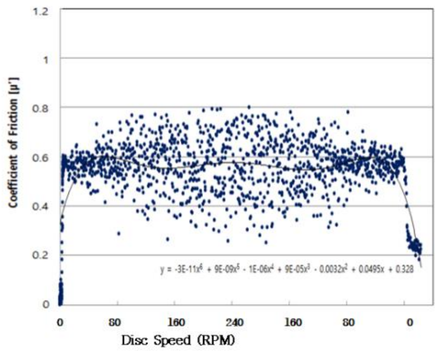


Figure 10. Friction velocity vs. the coefficient of friction (coated aluminum)

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3.3. Equivalent Friction Coefficient and Analysis

Friction coefficient from the friction experiment was calculated as equivalent friction coefficient which shall be applied to the actual belt system. Figure 11 shows a Multiple groove pulley and the forces acting on the V-belt pulley.

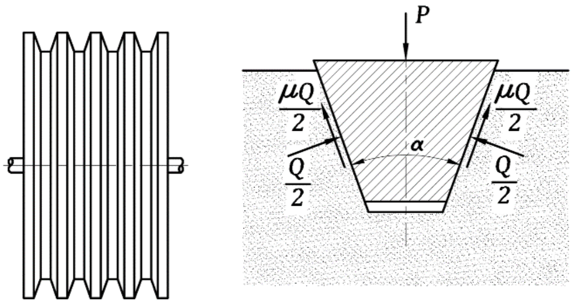

Figure 11. Multiple groove pulley

From Figure 11, the equivalent friction coefficient μ' is obtained as follows.

$$\mu' = \frac{\mu}{\sin\frac{\alpha}{2} + \mu\cos\frac{\alpha}{2}} \quad (3)$$

where α is the angle of the groove.

I have substituted the friction coefficient value from aluminum and coated aluminum pulley experiment to equation (3) to deduce equivalent friction coefficient in Figure 12 and Figure 13. In Figure 12, the results show that, while increasing speed, raw aluminum has a maximum equivalent friction coefficient 0.62 at the maximum 240rpm. Friction coefficient showed a gradual increase and decrease when the rotational velocity changed, and there is no section which has a constant friction coefficient.

On the other hand, in Figure 13, coated aluminum showed maximum equivalent friction coefficient is 0.73 at the beginning of velocity increase. In addition, from the beginning of the rotation, the equivalent friction coefficient is around 0.66, and the value is maintained almost uniformly.

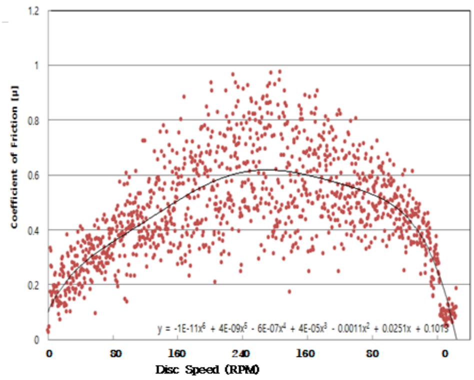

Figure 12. The equivalent friction coefficient of raw aluminum

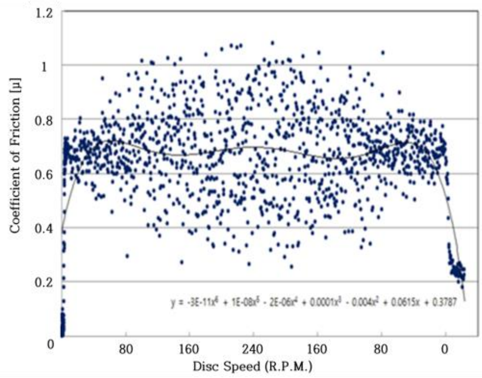

Figure 13. The equivalent friction coefficient of coated aluminum

Overall, the friction coefficient of coated aluminum increases steeply at the beginning and maintains an almost constant value over the entire interval from the beginning of acceleration to around 40rpm when decelerating. The value of the constant equivalent friction coefficient is approximately 0.66. It is expected that there will be little sliding while accelerating and decelerating. However, according to friction test[5], raw aluminum slips easily at the point of the acceleration and deceleration of rotational velocity compared to coated aluminum.

4. Conclusion

In this study, pin-on-disk friction test was performed friction between a belt made of synthetic rubber and anodizing coated pulley made of aluminum.

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The results show that equivalent friction coefficient of coated aluminum increases steeply at the beginning and the value is maintained at around 0.66 in a stable manner from the beginning of acceleration, and also during deceleration till reaching around 40rpm. This indicates that the coated aluminum will not slip in acceleration or deceleration. So we can say coated aluminum is suitable for manufacturing pulley because it shows a similar frictional tendency to steel. However, raw aluminum is inappropriate for pulley manufacture since it is slippery compared to steel. The pulley made of anodizing coated aluminum can be used to reduce the weight of the power transmission system in comparison to steel and increase the power transmission efficiency compared to raw aluminum.

5. Acknowledgements

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