Development of High-performance Phenolic Resin Idler Pulley

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Resins idler pulleys in automotive engines are increasingly used for improving fuel efficiency through weight reduction of automobile accessories. Phenolic resin is suitable for idler pulleys due to its characteristics of superior mechanical strength, dimensional stability, chemical resistance and cost. But it is not sufficient in wear resistance for use in contaminated environments such as road dust or thermal shock resistance in metal-inserted molding.

A new resin material with improved wear resistance to foreign materials and with improved thermal shock resistance was developed by adding an optimal anti-wear agent and optimizing the compounding ratio for moldability.

The idler pulley with this phenolic resin directly molded to the bearing has been evaluated on its basic bearing performance. And the new phenolic resin idler pulley with superior durability, small size and light weight was developed through optimum designing.

Key Words: *phenolic resin, idler pulley, wear*

1. Introduction

Every automaker has been improving fuel efficiency to cope with environmental issues. One way to obtain higher efficiency is to reduce component weight by using resin materials. Idler pulleys used for engine belt systems are also needed to change from conventional steel type to resin material type. A conventional resin idler pulley could not satisfy performance requirements such as mechanical strength, dimensional stability, heat resistance, chemical resistance, wear resistance and cost. To meet these requirements, a new phenolic resin was developed. Using this material, the new high-performance phenolic resin idler pulley was developed, which was designed by optimizing not only the dimensions of resin part from the evaluation result of strength and durability but also the bearing specifications such as internal clearance and lubricating grease.

2. Application of Idler Pulley

There are two basic types or uses of idler pulleys, one used as a timing belt to transmit power from the engine and the other is an auxiliary idler pulley. Each idler pulley has their own configurations, for example, plain pulleys are in contact with the back of the belt of both timing belt and accessories, and toothed pulleys match the shape of the tooth in timing belt. As for auxiliary belts, there are V-ribbed pulleys which match the groove shape of poly V-belts. **Figure 1** shows examples of the belt layouts of the timing belt and auxiliary belt, and **Fig. 2** shows examples of the structure of V-ribbed pulleys.

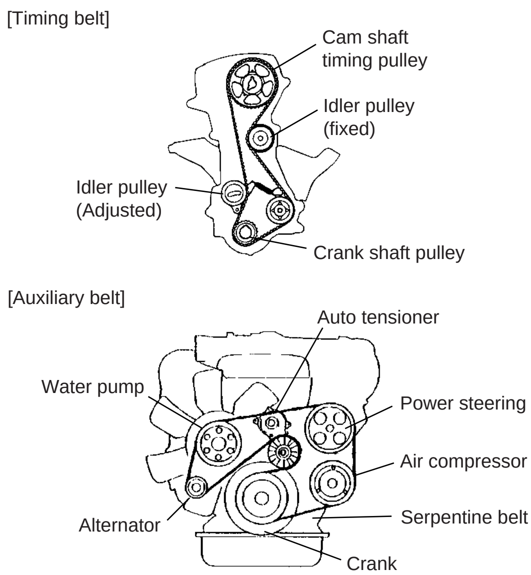


Fig. 1 Belt layout

Fig. 2 Structure and view of poly V-ribbed pulley

3. Material Development

Phenolic resin is a suitable material due to its mechanical strength, dimensional stability, chemical resistance and cost. However, when molded with an inserted metal, it is necessary to improve wear resistance in dusty conditions and thermal shock resistance. Therefore, it was necessary to take into account wear resistance in dusty conditions and thermal shock resistance in developing a new phenolic resin.

3. 1 Wear Resistance under Dusty Conditions

It is presumed, as shown in **Fig. 3**, that wear is progressing when dust is selectively attacking the resin around the glass fiber which was added as reinforcement.

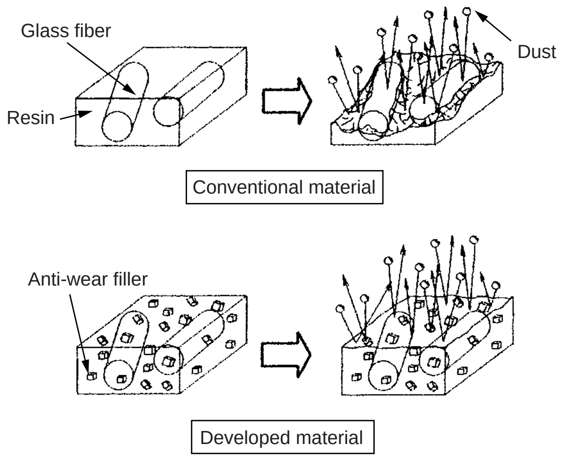


Fig. 3 Mechanism of wear progressing

For this reason, wear and abrasion resistance of materials which contain various anti-wear fillers of powders or fibers, shown in **Table 1**, were evaluated.

Table 1 Wear prevention fillers

Powder type	Clay, Silica Powder, Artificial marble, Wollastonite
Fiber type	Zinc oxide, Aluminum borate

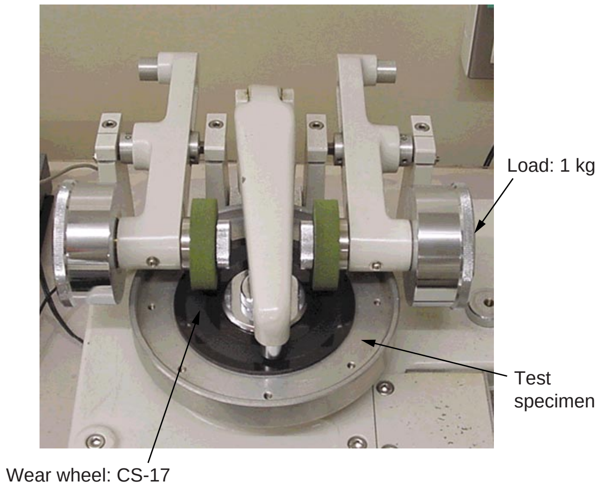


Fig. 4 Tabor wear tester

3. 1. 1 Tabor Wear Test

Wear resistance was evaluated using a tabor wear tester, as shown in **Fig. 4**. This tester is commonly used for evaluating the anti-wear performance of materials. Silica powder was proven to be the most effective for wear and abrasion resistance (**Fig. 5**).

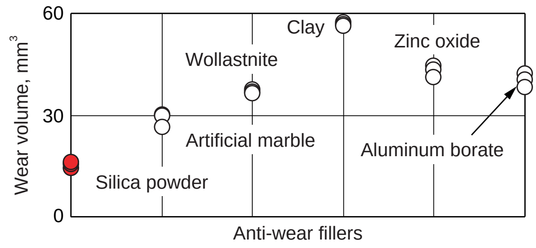


Fig. 5 Effect of various kinds of wear prevention fillers

To determine the content of the silica powder, the next step evaluation was done. The evaluation concluded that, to attain the necessary wear improvement and abrasion resistance, the filling content should be 30 wt% or more. (**Fig. 6**)

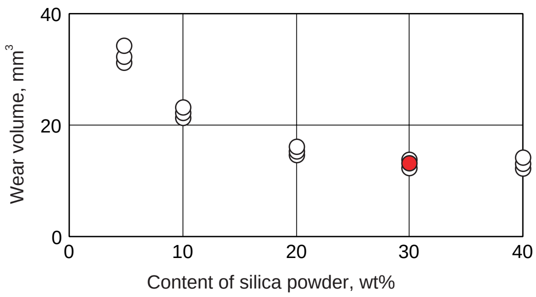


Fig. 6 Relation between amount of silica powder and wear

However, the silica powder may cause problems on the durability of such facilities as metal molds and injection machines due to its hardness (HV 1 300). Moreover, the aggressiveness of the silica powder varies depending on its shape, particle size and filling content. In order to solve these problems, the optimization of shape and the size was completed without changing the filler content, which might have influenced wear and abrasion resistance.

3. 1. 2 Dry Dust Wear Test

The pulley was molded using the developed resin that had the best wear resistance. The endurance test was performed in a dusty condition using the belt layout shown in **Fig. 7**. The belt was rotated for specified time to evaluate the wear of the inclined surface of the pulley.

As a result of the testing, the developed material was found to have excellent wear and abrasion resistance under a dusty condition. The wear of the developed material was 1/2 or less compared with that of the conventional material (**Fig. 8**).

It can be noted in the developed material that there is high concentration of wear resistant fillers among glass fibers and that the resin concentration is smaller than conventional material as shown in **Fig. 9** in the worn surface.

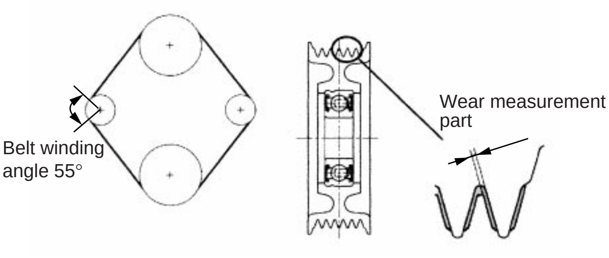


Fig. 7 Belt layout and wear measuring section

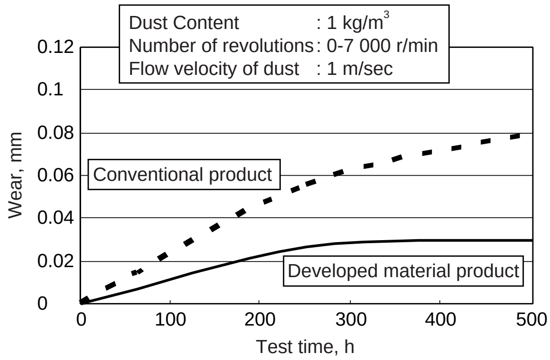


Fig. 8 Result of dust durability test

3. 2 Thermal Shock Resistance

Cracks were generated within 50 to 500 cycles in the thermal shock test. Therefore, it was concluded that the cracks generated not only due to the thermal stress caused by the difference in each linear thermal expansion of the resin and the metal, but also the complex stress of the residual stress caused by mold shrinkage and the after-shrinkage stress caused by heat cycling and progress of solidification reaction. The majority of failed parts indicated that the cracks initiated near the weld part. Therefore, it was assumed that cracks would not initiate if the following relational expression (1) was fulfilled in the newly developed material.

Fatigue strength of weld >
Thermal stress + Residual stress +
After-mold shrinkage stress (1)

Thermal stress, residual stress, and after-mold shrinkage stress can be reduced by increasing inorganic materials. This is the same for improving the wear resistance, as shown in the previous section. Therefore, to improve both thermal shock resistance and weld strength, the hardening characteristic and the flow property of the resin have been improved.

3. 2. 1 Weld Strength

Cure rate (= E/②), which was calculated from the measurement result by curelastometer shown in **Fig. 10**, was used as an index of the improvement. **Figure 11** shows the relation between the cure rate and weld strength.

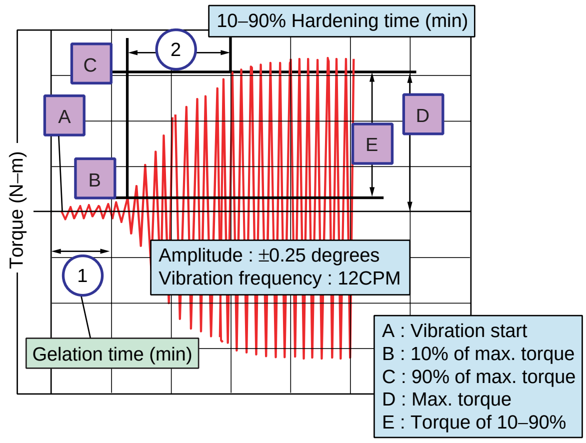


Fig. 10 Measurement result of hardening characteristics

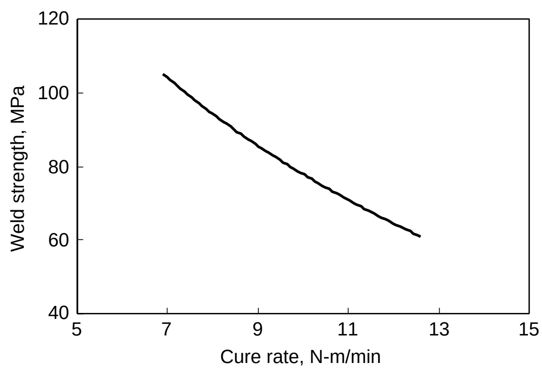
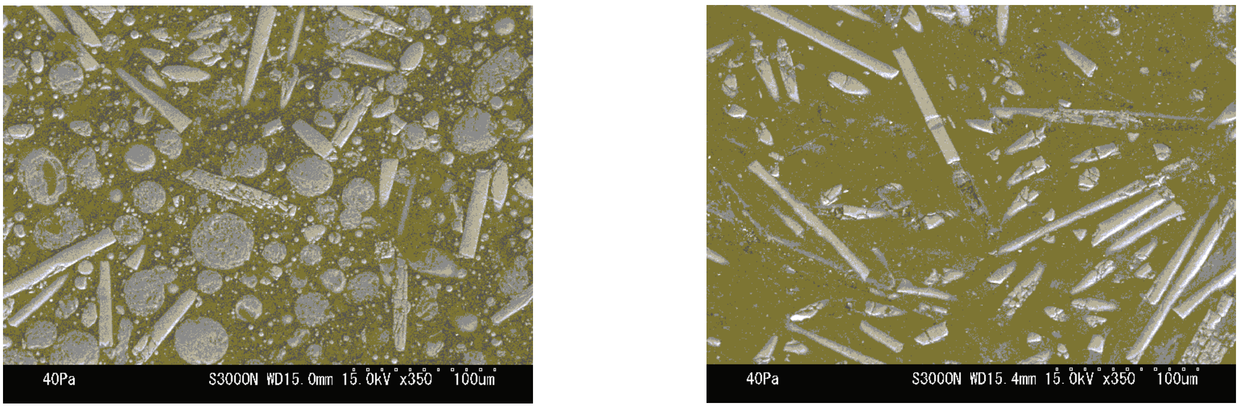


Fig. 11 Relation between cure rate and weld strength



(a) Developed material

(b) Conventional material

Fig. 9 Worn surface of sample after test

3. 2. 2 Thermal Shock Test

The fatigue test was done using weld test specimens. As a result, the fatigue strength of the newly developed material was greatly improved compared with that of the conventional material (**Fig. 12**). An additional thermal shock test (–40℃ × 30 min ↔ 120℃ × 30 min) was conducted with the developed product and it was not damaged even when exposed to 2 000 thermal shock cycles (**Fig. 13**).

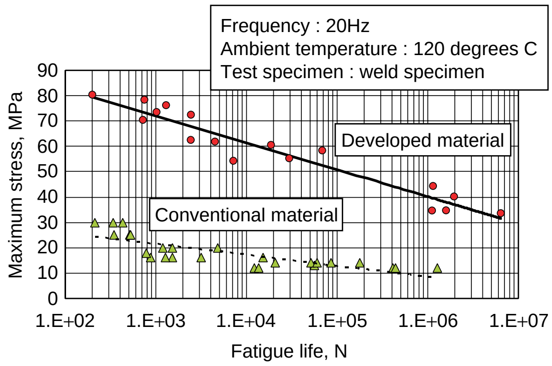


Fig. 12 Result of fatigue test at high temperature

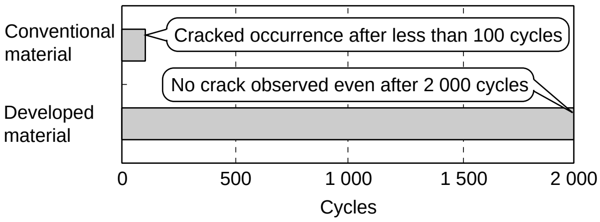


Fig. 13 Result of thermal shock test

4. Development of Pulley

Reinforcing ribs are often used between the inner hub and outer rim. This is done to improve the rigidity of the pulley against the belt load when multiple V-grooves type is used, as shown in **Fig. 14**. The reinforced ribs cause the inside diameter of the pulley to become polygon shaped. This out of roundness can possibly cause bearing noise. The reinforced ribs can also cause extra wind noise. Therefore the idler pulley without ribs was developed, as shown in **Fig. 15**. The required strength was obtained by optimizing the thickness of the inner hub and the outer rim of the pulley. Three types of samples were prepared to investigate the optimized resin thickness. These were approximately 50%, 75% and 130% of t_1/t_0. Where, t_0 is the smallest thickness of the bearing outer ring and t_1 is the thickness of the bottom of V-groove and the outer rim of the pulley.

4. 1 Dimensional Stability

Because any significant decrease in the belt tension due to thermal shrinkage of the resin is a major concern, the amount of shrinkage of the pulley under high temperature was evaluated (**Fig. 16**). A 130% thickness ratio was used for the test. It was found that 90% of the thermal shrinkage occurs within 50 hours. The final shrinkage percentage of 0.3% was almost the same for 120℃ and 150℃, though the shrinkage speed at 150℃ ambient was slightly faster. For typical idler pulleys (~ϕ 100mm), 0.3% diameter shrinkage does not result in significant reduction in the belt tension.

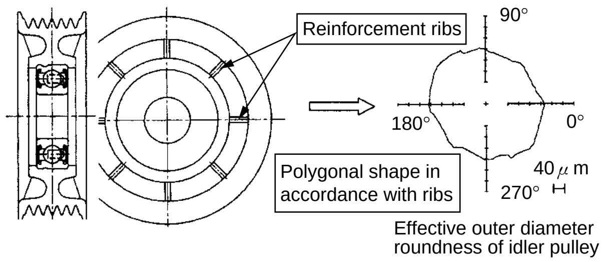


Fig. 14 Shape of conventional idler pulley (with reinforcement ribs)

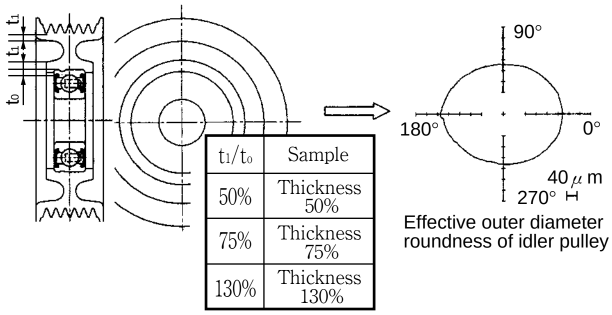


Fig. 15 Shape of developed idler pulley (without reinforcement ribs)

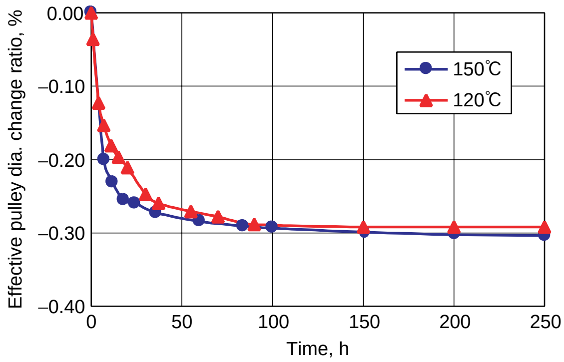


Fig. 16 Measurement result of change rate in effective pulley diameter.

4. 2 Evaluation of Radial Strength

Because mechanical strength of resins is inferior to that of steels, optimized dimensions are necessary to secure the required strength. As a result of FEM analysis of the idler pulley under the applied belt load, it was found that the main stress was generated at the bottom of the V-grooves, as shown in **Fig. 17**.

The analysis was confirmed with an actual destructive test. This was accomplished by applying loads through a steel belt. V-groove bottom was damaged as a result of FEM analysis. The actual stress calculated during the destructive test was very close to the values calculated by FEM analysis, as shown in **Fig. 18**.

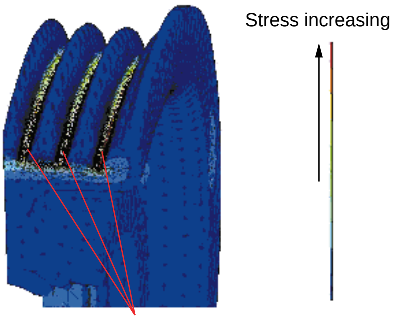


Fig. 17 Result of FEM

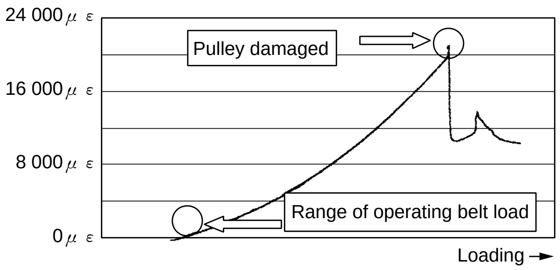


Fig. 18 Measurement result of strain at the damaged area

Figure 19 shows the measurement result of radial strength* ratio (load at which the idler pulley is damaged). In idler design, the radial strength can be increased by enlarging the resin thickness at the outer hub's rim. To obtain the radial strength that is sufficiently higher than the belt-breaking load, the resin thickness ratio of 130% is needed.

(*Shown as the ratio to the maximum value of the fracture strength of 6-ribbed rubber belt)

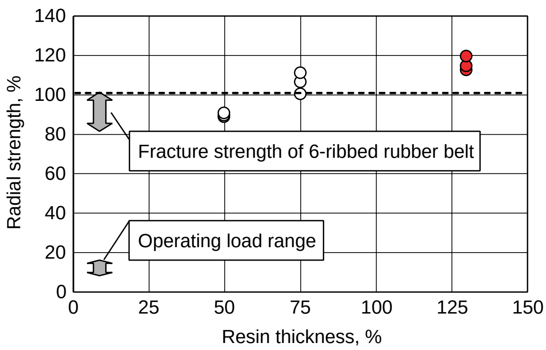


Fig. 19 Measurement result of radial strength

4. 3 Turning Torque

Since the linear expansion coefficient of the metal (outer ring of bearing) and the resin (pulley) are different, the holding force between the outer ring and the pulley decreases under high temperature and slipping between them may occur. To combat this problem, an eccentric groove is made on the bearing outer ring causing a wedge with the resin preventing any slippage.

A shaft connected to the outer ring was attached to a torque detector and the turning torque* between the pulley and the outer ring was measured.

The torque increases 200% or more, as seen in **Fig 20**. In comparison with the torque without an eccentric groove, the maximum turning torque is obtained at the thickness ratio of 130% (**Fig. 20**).

(*Shown as the ratio to the turning torque without eccentric groove)

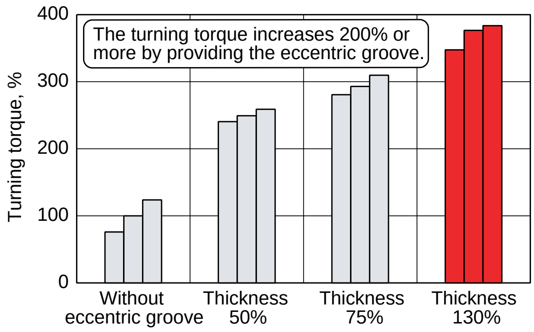


Fig. 20 Measurement result of turning torque

As mentioned above, the thickness ratio of 130% is needed at the outer rim to obtain the radial strength larger than the belt-breaking load. Moreover, it is preferable to set the resin thickness around the bearing outer ring to the same thickness as the outer rim for best molding results. Therefore, the thickness ratio of 130% was chosen for the developed idler pulley in consideration of the mechanical strength and the resin moldability.

4. 4 Thermal Shrinkage of Bearing Outer Raceway Diameter

Because the decrease of bearing internal radial clearance due to the heat shrinkage of the resin is of concern, modification of the outer raceway diameter was investigated. This investigation followed the conditions shown in **Table 2** (**Fig. 21**).

Table 2 Test conditions

Measurement time	After 0, 10, 30, 70, 150, 250 h
Ambient temperature	120℃
Samples	50% and 130% in resin thickness (n = 3)

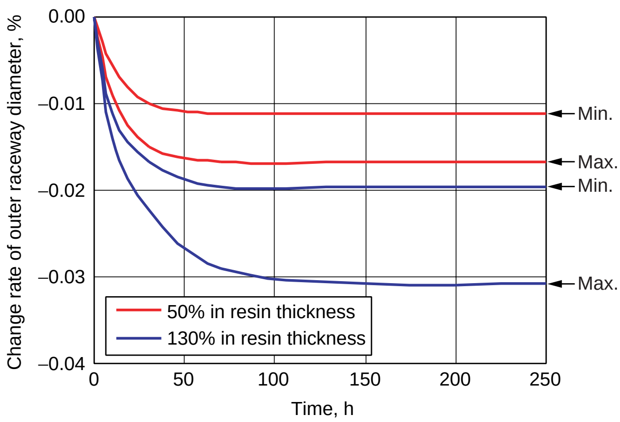


Fig. 21 Change rate of outer raceway diameter

It was concluded that the shrinkage of bearing outer raceway diameter was greater in the idler pulley with higher resin thickness. To prevent noise and seizure, due to decreasing of the bearing internal radial clearance during the initial engine warm-up, the bearing internal radial clearance in the developed idler pulley considered the anticipated shrinkage of the outer raceway.

4. 5 Influence of Eccentric Groove

The bearing outer ring roundness was measured due to the concern that the use of the eccentric groove would reduce the mechanical strength of the part. There was no correlation between the bearing outer ring roundness distortion and the eccentric groove and/or its eccentricity direction, as shown in **Fig. 22 (a)~(c)**. It was confirmed that, even for the outer ring with 130% resin thickness, the use of eccentric groove did not reduce its strength.

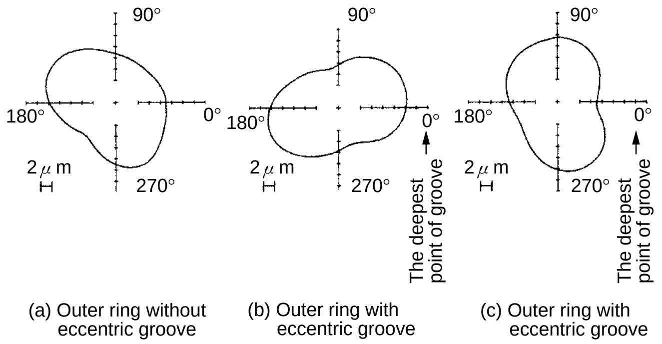


Fig. 22 Roundness of outer ring (130% resin thickness)

4. 6 Evaluation of Fatigue Strength of Idler Pulley

The newly developed idler pulley configuration does not generate levels of stress as to cause fatigue fracture to the resin part. An oblong hole was drilled mechanically (circumferential angle: 120°) on the resin part, as shown in **Fig. 23**, in order to generate high levels of stress to cause fatigue fracture. Using this sample, a rotational fatigue test was carried out under the temperature of 100℃ to confirm the fatigue strength of the idler pulley.

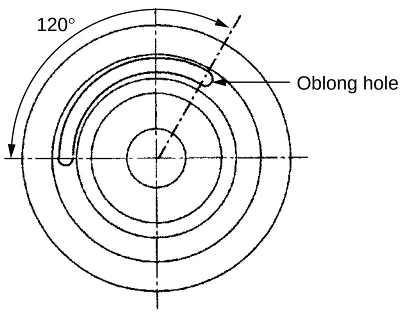


Fig. 23 Sample configuration for fatigue test

Necessary fatigue strength in actual use was estimated to be 1×10^9 revolutions, which was calculated by taking into consideration the average rotational speed. The average rotational speed was calculated by using the average velocity of cars and the guarantee mileage.

The fatigue strength of the developed idler pulley satisfied the necessary 1×10^9 revolutions, as shown in **Fig 24**. (The vertical axis is the percentage of the bearing strength of a 6-ribbed rubber belt.)

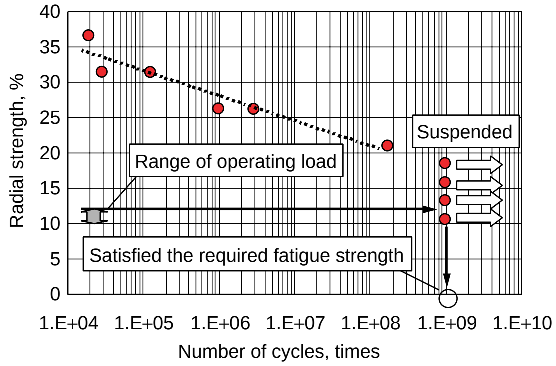


Fig. 24 Result of rotational fatigue test

4. 7 Bearing Life

The decrease in the bearing fatigue life of resin idler pulleys is a concern because they are inferior in heat dissipation as compared to steel pulleys. Therefore, the bearing life was evaluated under several bearing temperatures. The bearing temperature is affected by ambient temperature, rotational speed and belt tension. The temperature of the inner ring was measured under various conditions with the belt tension set to the upper level (**Fig. 25**).

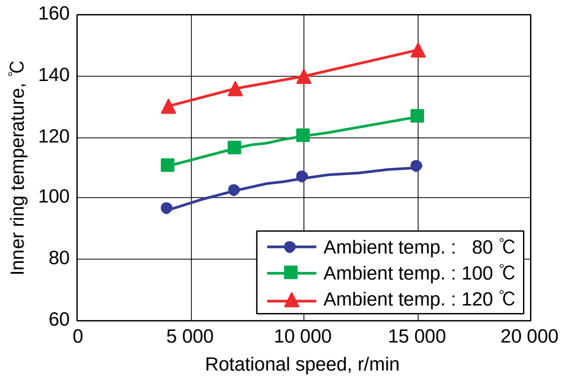


Fig. 25 Measurement result of inner ring temperature

Idler pulleys are generally used with the ambient temperature of 80~100℃. A bearing temperature of 148℃ was measured under the maximum rotational speed of 15 000 r/min using an abnormally high ambient temperature, 120℃. This temperature is in the heat resistant range for component parts of a bearing and no functional damage of parts occurs.

Since the total required cycles in actual use was estimated at 1×10^9 revolutions, an endurance life of 1 700 hours is required using the condition of 10 000 r/min. The bearing fatigue life was calculated considering bearing temperature and at 10 000 r/min. This result was shown in **Fig. 26** as the short dashed line. The developed pulleys had enough durability to exceed 1 700 hours in the actual use. As a result of the endurance test, the bearings life in the actual usage temperature achieved the required life. The testing and calculations confirmed that the developed idler pulley had the required durability.

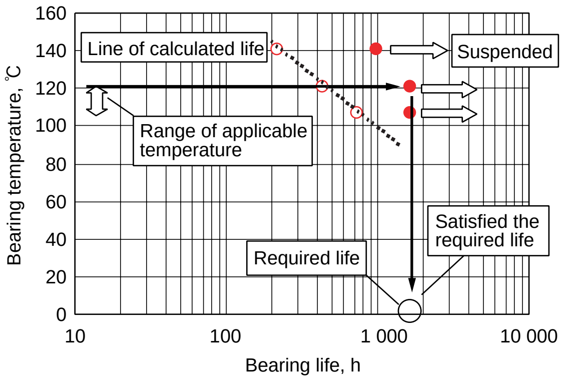


Fig. 26 Bearing life evaluation

5. Conclusion

Most current phenolic resin materials could not be used in today automotive pulley applications because of the inability to handle the rugged conditions. By adding an optimal anti-wear agent, optimizing the resin hardening characteristics, and improved flowability, a superior phenolic resin material was developed. In addition, resin pulley dimensions and bearings specification were modified. This new material and design can be used for automotive pulley applications, where the resin pulley is molded directly on the bearing. The material shows superior wear characteristics against road dust and thermal shock resistance.

Idler pulleys using this new material are highly durable, compact and lightweight.

In Conclusion, idler pulleys using the new phenolic resin weigh only 65% of the conventional steel design. This reduction of mass aids them in being more efficient and help in improving fuel consumption.

(This paper is a reedition of the article[1)] presented in the SAE World Congress held in Detroit from March 3 to 6, 2003)

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