1. Introduction

In a drive shaft, a spline section is provided in the intermediate shaft, that slides axially (see Fig. 1). In many cases an involute shaped spline is used. But power loss due to sliding resistance is large when torque is loaded, and becomes the source of harmful vibration in some cases.

Thus, for the purpose of reducing sliding resistance, sliding coefficient and vibration (sound) when a torque is loaded and improving abrasion resistance, the method of applying a coating using polyamide resin (hereinafter referred to as "polyamide coating") to the involute spline section is often used. Besides polyamide coating, there is an example of utilizing a ball spline to reduce sliding resistance and friction coefficient, but polyamide coating is typically used because of its lower cost. In polyamide coating of a spline section, a processing method of fluidized-bed coating is mainly used. However, for the purpose of improving sliding characteristics, improving processing freedom, and reducing waste, a new processing technology (electrostatic powder coating) has been developed for polyamide coating which has enabled to improve sliding performance of drive shafts. This paper introduces the overview of the new processing technology for the polyamide coating, its sliding characteristics and evaluation results.

2. Outlines of a Drive Shaft

The drive shaft used between the axle and transmission of a wheel loader, a machine used in the construction industry, is a practical example of a drive shaft for which the reduction of sliding resistance of the spline section is necessary (see Fig. 2). The wheel loader has an articulated structure that enabled to turn the front side of the vehicle around the connection section when the vehicle turns. The sliding operation is frequently carried out while transmitting torque at the spline section of the drive shaft, polyamide coating is often applied to the spline section for improving performance (see Fig. 3, Fig. 4, Fig. 5).

Key Words: drive shaft, polyamide coating, sliding resistance, spline
3. Outline of Polyamide Coating Process

Table 1 gives the process, characteristics and problems concerning the existing and newly developed coatings and Fig. 6 shows the comparison of these coating processes.

4. Sliding Characteristics and Vibration Isolating Effect of Developed Coating

4.1 Sliding Characteristics of Developed Coating

In order to compare sliding characteristics of the newly developed and existing coatings, a comparison test of specimens of the same thickness was conducted using an abrasion and wear test machine. Table 2 gives the test conditions, Fig. 7 shows the schematic diagram of the test machine and Fig. 8 shows the test results.

As the result of the abrasion and wear test, it was confirmed that the sliding characteristics (wear and friction coefficient) of the newly developed coating were equal to that of the existing product.

**Table 1** Comparison of polyamide coating process

<table>
<thead>
<tr>
<th>Method</th>
<th>Developed coating (electrostatic powder coating)</th>
<th>Existing coating (fluidized-bed coating)</th>
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<tbody>
<tr>
<td>Process</td>
<td>Shot blasting → degreasing → undercoat → electrostatic powder coating (polyamide powder) → induction heating</td>
<td>Shot blasting → degreasing → undercoat → furnace heating → fluidized-bed coating (polyamide powder) → finish broaching</td>
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</table>
| Characteristics | · Finish processing abolished (no resin waste).  
· Because polyamide powder is melted only by raising surface temperature, work heating temperature is low. | · Because finish processing is carried out, precision is good. |
| Problems     | · Control of dimension precision and coating thickness is necessary when coating. | · Many processing steps.  
· Each finish process broach is required for each size.  
· Work heating temperature is high.  
· Resin waste is produced at finish process. |
### 4. 2 Coating Thickness and Wear Amount, Vibration Isolating Effect of Developed Coating

1) The relationship between coating thickness and wear amount of the developed coating was evaluated using the abrasion and wear test machine discussed in section 4.1. The results are shown in Fig. 9. Specimens having a coating thickness ranging from 100 μm to 300 μm were tested. The results showed wear was slight for coatings of 200 μm or less in thickness.

2) The relationship between coating thickness and vibration isolating effect was evaluated using an impact tester. Table 3 gives test conditions of the impact test, Fig. 10 shows the test schematic diagram, and Fig. 9 shows the test results. Specimens having a coating thickness ranging from 0 μm to 400 μm were tested. The results showed a significant decrease in vibration amplitude for coatings up to 200 μm in thickness. For coatings thicker than 200 μm, there was little improvement over the decrease achieved at 200 μm.

Figure 9 shows that when the coating thickness was about 200 μm, the optimal result for both wear resistance and vibration isolating effect was achieved.

### 5. Bench Test Results of Developed Coating

Using specimens of drive shaft spline sections coated with existing and developed coatings, a sliding comparison bench test was conducted. The following items were studied:

(a) Temperature change over time of the spline sleeve at the outer diameter (Fig. 11).

(b) Condition of polyamide coating (spline teeth coating thickness) after completion of the test.

Figure 11 shows the specimen, Table 4 gives the test conditions, Table 5 gives a summary of test results, and Fig. 12 shows the relationship between the temperature at the outer diameter of spline sleeve over time.

From these results, it was confirmed that the sliding characteristics (wear amount, heat generation) of the developed coating at the coating thickness of 200 μm performed at least as good as the existing coating. This agrees with the tendency for wear amount to be slight at coating thickness of 200 μm or shown in the section 4.2. It is thought that heat generation of sliding sections could be suppressed by making coating thickness 200 μm.
6. Conclusion

By using the new process technology of electrostatic powder coating followed by induction heating, and controlling the coating thickness to 200 μm, the following can be concluded:

a. vibration isolating effect was optimized.

b. sliding characteristics were improved.

c. overall performance of the spline section improved.

Furthermore, polyamide coating by electrostatic powder coating does not require the broach finish processing step, which provides more freedom in designing complex shaped parts.

Finally, the powder does not adhere to the work-piece thus it can be recovered and recycled. The technology therefore does not produce waste and is friendly to the environment.

Reference

1) Daicel-Degussa Ltd.: Daiamid Nylon 12, 1006 (revision 8) (1995)