1. Introduction

Machine tools process workpieces using relative motion between the tools and workpieces; therefore, performance of the guideway which moves either the tool or workpiece has a significant impact on processing accuracy. There are two types of guideways, rolling type and sliding type, which are selected depending on the use. The rolling type, such as a linear guide, moves tools or workpieces with rollers. The sliding type either uses lubricating oil on the guideway for sliding between two metal surfaces or uses a plastic sliding sheet adhered to one of the metal surfaces for sliding between the other metal surface. For the sliding sheet material, polytetrafluoroethylene (PTFE) is used for its low friction and high anti-galling properties. The properties of the plastic sliding sheet play a critical role since the sliding surface is in mixed lubrication condition.

In this article, we describe the sliding sheet for machine tool guideways made of BEAREE FL3307, which is PTFE blended with special filler material, for improved friction wear properties under the mixed lubrication condition.

2. Characteristics of various guide types

Table 1 shows the features of different guide types. The rolling guide type has low friction resistance and is capable of moving tools or workpieces at high speed without causing stick slip; therefore, it provides high processing accuracy. However, since the area of contact is small due to line contact of the rollers, rigidity is low and vibration may occur under heavy load. Therefore, it is not suitable for processing objects with high cutting resistance.

The sliding guide type has a large area of contact due to plane contact leading to a high rigidity; therefore, it is suitable for processing objects with high cutting resistance. By using a plastic sliding sheet on the guideway, a high vibration damping property can be achieved and stick slip can be largely prevented compared to sliding between two metal materials. In addition, seizure can be avoided even under poor lubrication conditions.

Fig. 1 shows an overview diagram of the machine tool sliding guide type. Recently, as the cases of processing
difficult-to-cut materials, such as carbon fiber reinforced plastics, are increasing, machine tool models with sliding guideways using plastic sliding sheets are becoming more popular due to their superior processing accuracy with low vibration even when the cutting resistance is high.

3. Performance required for plastic sliding sheet

In the sliding guideway type, oil grooves are created on the guideway to facilitate the formation of a lubricating film. In addition, scraping is also applied on the surface to create a uniform contact condition with micro dimples of several tens of μm². Fig. 2 shows the surface conditions before and after scraping on a BEAREE FL3307 plastic sliding sheet. Scraping is done by hand by skilled technicians. The plastic sliding sheet has an advantage over metal material for easy scraping.

The micro dimples on the guideway created by scraping increases lubricating oil retention and stabilizes friction resistance to a low level. When the plastic sliding sheet wears out or is deformed by the load, the dimples on the sliding surface are reduced which increases the friction resistance; therefore, the plastic sliding sheet requires good wear and compression creep resistance.

For machine tools, high speed transfer of tools or workpieces is required in order to reduce machining cycle time. Therefore, it is desirable for plastic sliding sheets to have low starting static wear coefficient and dynamic friction coefficient, as well as low contact pressure and speed dependency.

4. Features and manufacturing process of PTFE plastic sliding sheet

PTFE has low friction coefficient, high non-adhesive properties, and a high heat tolerance up to a continuous operating temperature is 260˚C. It also has excellent chemical and weathering resistance enabling its use on the guideway, which is in contact with lubricating oil and coolant for a long time. PTFE alone, however, has poor friction and compression creep resistance and a large linear expansion coefficient; therefore, fillers such as glass fiber, carbon fiber, bronze powder, graphite, etc. are blended into the material. The friction/wear properties change depending on the fillers and blend ratio. It is important to choose the right filler and blend ratio for the specific use.

Fig. 3 shows the manufacturing process of sliding sheets for machine tool guideways. As PTFE has high melt viscosity preventing injection molding, a plastic sheet of 0.8 to 1.5 mm thickness is manufactured by skiving the material from a compression molding. Skiving is a manufacturing process to obtain sheets from the mold material by slicing it with a blade while rotating the mold material.

Since PTFE has high non-adhesive properties and cannot be adhered as is, the surface is chemically etched by treatment liquid so that it can be adhered. NTN has prepared an adhesive dedicated for adhering the plastic sheet on the guideways made of cast iron, etc. which has resistance against lubricating oil and coolant. The tensile shear strength of cast iron and BEAREE FL3307 plastic sliding sheet using this adhesive is 6 MPa and has a sufficient safety factor against frictional shear of 0.06 MPa calculated from the used contact pressure and friction coefficient (when contact pressure is 1 MPa and friction coefficient is 0.06).
5. Performance of NTN plastic sliding sheet

A comparison of the performance of 3 types of plastic sliding sheets (BEAREE FL3307 (hereafter, NTN product), glass fiber (GF) blended PTFE (hereafter, Comparison Product A) and carbon fiber (CF) and bronze powder blended PTFE (hereafter, Comparison Product B)) was performed. Table 2 shows the comparison of performance.

**NTN product** has higher tensile strength and elongation with superior friction wear properties and compression creep properties. Details of the test method and results of the friction wear and compression creep properties are described below.

### 5.1 Friction wear test method

The reciprocating motion tester shown in Fig. 4, which simulates the guideway of machine tools, was used for the friction wear test. A vertical load was applied to a metal block test piece, which has the plastic sliding sheet adhered to it, and the metal mating material was set in reciprocating motion. The plastic sliding sheet was not scraped but oil grooves were applied after adhesion. The metal mating material is meehanite cast iron with surface roughness of Ra 0.25 μm which is induction hardened and polished on the sliding direction. Lubricating oil for machine tools was applied on the sliding surface.

The friction coefficient was calculated by dividing the friction force, which was measured by the load cell attached to the mating material, by the vertical load.

### 5.2 Contact surface/speed dependency of dynamic friction coefficient

The dynamic friction coefficient was measured by changing the contact pressure and speed under the test condition shown in Table 3. Fig. 5 shows the relation between the contact pressure and the dynamic friction coefficient and Fig. 6 shows the relation between the speed and the dynamic friction coefficient.

The dynamic friction coefficient tends to decrease as the contact pressure increases. In the contact pressure dependency test, the dynamic friction coefficient of **NTN**'s product was slightly lower than the comparison products, and the dependency was small when the contact pressure was higher than 0.3 MPa. In the speed dependency test, the dynamic friction coefficient of **NTN**'s product was equivalent to or less than the comparison products with small speed dependency.

*Fig. 7 and 8 are the photographs of the plastic sheet of **NTN**'s product and Comparison Product A, taken by scanning electron microscope. Fillers are exposed on the sliding surface of the plastic sheet.*

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**Table 2** Comparison of features plastics sliding sheets

<table>
<thead>
<tr>
<th>Item</th>
<th>NTN product</th>
<th>Comparison product A</th>
<th>Comparison product B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheet material</td>
<td>BEAREE FL3307</td>
<td>GF blended PTFE</td>
<td>GF and bronze powder blended PTFE</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>20MPa</td>
<td>15MPa</td>
<td>13MPa</td>
</tr>
<tr>
<td>Elongation</td>
<td>220%</td>
<td>200%</td>
<td>180%</td>
</tr>
<tr>
<td>Static friction property</td>
<td>☐</td>
<td>△</td>
<td>△</td>
</tr>
<tr>
<td>Contact pressure dependency</td>
<td>☐</td>
<td>△</td>
<td>△</td>
</tr>
<tr>
<td>Speed dependency of dynamic friction coefficient</td>
<td>☐</td>
<td>△</td>
<td>△</td>
</tr>
<tr>
<td>Compression creep properties</td>
<td>☐</td>
<td>△</td>
<td>△</td>
</tr>
</tbody>
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*Good △ Fair*
In Comparison Product A, the direction of fiber filler material is random, with some only exposing the ends of the fibers. Fiber fillers are not likely to fall out when a frictional shear force is applied due to their shape; however, the friction coefficient does increase due to the resistance of the fiber end’s edges. This is also true with Comparison Product B, which is blended with carbon fibers. NTN’s product has fillers scattered on the sliding surface; however, these fillers are not fiber-like and not anisotropic; therefore, they are unlikely to increase friction coefficient. The sliding surface can easily form an oil film due to the oil grooves and micro dimples (from scraping); however, it is in mixed lubrication condition as the plastic sliding sheet is partially in contact with the mating metal material. When this contact becomes plane contact, lubricating oil is ejected, resulting in a higher friction coefficient. It is assumed that NTN’s product creates point contact at the exposed fillers; therefore, lubricating oil remains on the contact surface, resulting in a good lubrication condition and low friction coefficient.

5.3 Wear properties

Fig. 9 shows the specific wear rate of NTN’s product when tested for wear under the test conditions shown in Table 4. Specific wear rate is the volume of wear per sliding distance per load, which is calculated from the measurements before the test and after the test. The smaller the specific wear rate, the better the wear resistance.

The specific wear rate of NTN’s product is very low at any speed and is superior in wear resistance.

6. Summary

In this article, we introduced the BEAREE FL3307 Plastic Sliding Sheet, used in the sliding guideways of machine tools. This material mix has low friction, low wear properties, and a small compression creep deformation rate, which contributes to higher speed and higher machining accuracy of machine tools.

We will continually improve our material blending technologies for lower friction/wear and develop products that meet the demands of higher functionality and energy efficiency in various fields.

References