Product Introduction and Complex Technology of Resin, Sintered Metal and Magnet for Growth Markets

1. Introduction

NTN’s Composite Material Products Division consolidates and integrates fluid dynamic pressure technology and technologies of NTN’s related companies, which include NTN Engineering Plastics Corp., NTN Powder Metal Corporation and Nippon Kagaku Yakin Co., Ltd., to develop unit module products to be used in the automotive and industrial industries. Currently, NTN is working specifically on the following activities, focusing on the growing markets such as electric vehicles and energy:

1) Development and proposal of not only components but unique unit products by combining resin and sintered metal
2) Development of light and compact sliding bearings as an alternative to rolling element bearings
3) Sintering of machine parts which require high strength
4) Product development for industrial and automotive industries applying magnetic material technologies
5) Proposal of “only one” technology including amorphous magnetic material into growing markets

In order to meet the market to be diversified, NTN is working to develop the future markets while creating new material properties by promoting fusion of each technology and Composite Materials which are applying tribology, bearing material, high-precision processing technology and magnetic materials. This paper reports the Developed Products of Composite Products for the further growth markets.

2. Product line and production system of Composite Material Products Division

NTN’s composite material products include mainly resin, sintered metal, and magnetic materials. These products are produced by the NTN’s four related companies shown in Fig. 1. Key products developed by the NTN companies are introduced in Section 3 and the subsequent sections. Various technologies/products are also covered by different articles.

Fig. 1 Products and production system of composite material products

* Composite Material Products Division
3. Resin material products

Resin components have a high degree of freedom for design and are used in diverse fields as alternatives to metal components since they are inexpensive and can be made lightweight, compact, and corrosion resistant. NTN develops and designs resin materials, specifically working toward higher product functionality by leveraging the resin properties and improving bearing load properties by creating composite material with metal. The following is the recent resin material:

(1) Resin sliding bearings\(^1\) for electric water pump

Use of electric and hybrid vehicles is increasing because of the reduction in CO\(_2\) emissions. Conventional vehicles driven by internal combustion engines are equipped with centrifugal pumps for circulation of radiator water for engine cooling. These are driven by the engine rotation which is transmitted to the pump shafts through the engine belts. Contrary to this, electric vehicles do not have engines and hybrid vehicles stop engines with a start/stop function. Therefore, electric pumps are required for inverters or engine cooling systems. These electric water pumps are mainly high-efficient and compact centrifugal pumps with magnetic drives.

Fig. 2 shows the structure of the magnetic-drive centrifugal pump. This structure allows fluid, such as antifreeze liquid, to flow by rotating impellers integrated with magnetic casing using the magnetic force of the magnet installed on the motor shaft as it rotates. As shown in Fig. 3, BEAREE AS5704 made of polyphenylene sulfide (PPS) resin with special filler blended in is used as the bearings in the center of the impeller. These bearings have sliding contacts between the internal bore of the bearing and the stationary shaft and the bearing side face and the thrust pad. These sliding contacts support the radial and axial loads respectively.

[Features]

(1) Friction in the water is 1/5 or less compared with sliding bearings made of universal PPS resin
(2) Reduced friction damage to mating material, such as stainless steel
(3) Larger degree of freedom for design due to injection molding
(4) Compatible with antifreeze, acid, and alkaline fluid

Table 1 shows a comparison of performance among typical sliding bearings used in fluid. Bearings made of carbon excel in wear resistance in fluid; however, they show a lower degree of freedom in shape because they are machined from formed materials and possess inferior crack resistance against impact. The cost is also a challenge. Since BEAREE AS5704 bearings are mainly made of PPS resin, they have superior properties in self-lubricity, chemical resistance, and a high degree of freedom in design using injection molding. It is easy to provide lubrication grooves on the internal surface of the bearing bores, end faces, and retainers (D-cut, projection, etc.) on the outer surface of the bearings which can be molded into a single piece without the machining process.

![Fig. 2 Structure of magnet drive centrifugal pump](image_url)

![Fig. 3 Plastic sliding bearings for electric water pump (BEAREE AS5704)](image_url)

**Table 1** Comparison of features various bearings

<table>
<thead>
<tr>
<th>Types of bearings</th>
<th>BEAREE AS5704</th>
<th>Carbon (graphite blended)</th>
<th>Phenol resin (graphite blended)</th>
<th>PTFE (graphite blended)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machining method</td>
<td>Injection molding</td>
<td>Machining</td>
<td>Injection/ compression molding</td>
<td>Machining</td>
</tr>
<tr>
<td>Wear resistance (under water)</td>
<td>□</td>
<td>□</td>
<td>△</td>
<td>X</td>
</tr>
<tr>
<td>Chemical resistance</td>
<td>□</td>
<td>□</td>
<td>△</td>
<td>□</td>
</tr>
<tr>
<td>Water absorption</td>
<td>□</td>
<td>X</td>
<td>△</td>
<td>□</td>
</tr>
<tr>
<td>Dimensional stability</td>
<td>□</td>
<td>□</td>
<td>△</td>
<td>□</td>
</tr>
<tr>
<td>Crack by impact</td>
<td>□</td>
<td>X</td>
<td>△</td>
<td>□</td>
</tr>
<tr>
<td>Deformation by impact</td>
<td>□</td>
<td>□</td>
<td>△</td>
<td>□</td>
</tr>
<tr>
<td>Degree of freedom for design</td>
<td>□</td>
<td>X</td>
<td>△</td>
<td>□</td>
</tr>
<tr>
<td>Price</td>
<td>□</td>
<td>X</td>
<td>□</td>
<td>□</td>
</tr>
</tbody>
</table>
Fig. 4 shows the specific wear rate of BEAREE AS5704 and various PPS resin materials with glass fiber, carbon fiber, and PTFE resin blended in. AS5704 is superior in wear resistance when compared to other PPS materials because it has special filler materials added to the PPS resin.

Feed screws, which convert rotational motion of the motor to linear motion, are used for carrying units of medical and food equipment. Feed screws include ball screws and resin sliding screws.

Table 2 shows the comparison of their performance. Ball screws are superior in load capacity and screw efficiency, although they are an expensive option. In addition, as they are lubricated with grease, they are not suitable for use where dispersion of grease and deterioration due to high temperatures are a concern. On the other hand, resin sliding screws have lower load capacity but they do not require lubrication allowing for use in a broader range of applications, including vacuum or high-temperature ambient. They are also less expensive and quieter during operation.

NTN’s sliding screws made of precision resin consist of PPS resin nuts and stainless steel screw shafts as shown in Fig. 5. Due to the PPS resin having improved wear/friction property by blending solid lubricant, it also results in a longer life when compared to general-purpose resin sliding screws.

NTN has recently developed resin sliding screws for high load, which have been limited to lower load applications, and proposing them for a cleaner production environment and increased load capacity. NTN has created a composite nut applying PPS resin sliding material onto the surface of threads of a brass nut as indicated in Fig. 6, by injection molding, and increased the heat transfer and load capacity. The brass has a special surface treatment to improve adhesion with the resin. This composite structure improved not only the bearing load capacity but also durability.

The resin sliding screws for high load have twice the axial load capacity and 9-times higher nut static breaking load when compared to the conventional sliding screws. In addition, the life under high load condition is 3 times longer than the conventional resin sliding screws.

[Features]
Comparison with conventional products (NTN resin sliding screw)
(1) Permissible axial load: 2 times
(2) Nut static breaking load: 9 times
(3) Friction: 1/3

Table 2 Comparison of features various sliding screws

<table>
<thead>
<tr>
<th>Item</th>
<th>Ball screw</th>
<th>Resin sliding screw</th>
<th>Resin sliding screw for high load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lubrication</td>
<td>Required (grease)</td>
<td>Not required (can also be used with lubrication)</td>
<td>Not required (can also be used with lubrication)</td>
</tr>
<tr>
<td>Load resistance</td>
<td>□</td>
<td>△ ~ ○</td>
<td>○</td>
</tr>
<tr>
<td>Screw efficiency</td>
<td>□</td>
<td>△ ~ ○</td>
<td>○</td>
</tr>
<tr>
<td>Noise</td>
<td>△</td>
<td>○ ~ ○</td>
<td>○</td>
</tr>
<tr>
<td>Heat resistance</td>
<td>△</td>
<td>△ ~ ○</td>
<td>○</td>
</tr>
</tbody>
</table>

□ Excellent □ Good △ Fair

Fig. 5 Resin sliding screws

Fig. 6 Resin composite sliding screws for high load
(3) Hybrid PEEK bearings

The majority of power consumption of an air conditioner is occupied by the compressor. Therefore, higher efficiency is required to reduce energy consumption of an air conditioner. Fig. 7 shows the structure of a compressor and the installation positions of the bearings. The bearings are required to have improved friction/wear properties and resistance against heat (the refrigerant liquefied by over-compression can make the refrigerant oil leak from friction).

Therefore, NTN is developing hybrid PEEK bearings with improved friction/wear properties and resistance against being burnt using composite material of sintered alloy and PEEK resin.

Fig. 8 shows the structure of hybrid PEEK bearings. Different from polytetrafluoroethylene resin wrapped bushings made by the impregnation/sintering process on the sintered intermediate layer of a steel plate, these bearings are made with a layer of 0.5 mm thick PEEK resin applied on the internal surface of the sintered alloy bushing by injection molding. PEEK resin is suitable for injection molding and excels in heat, wear, chemical, and fatigue resistance. In addition, it also considerably improved heat transfer properties in the composite structure with metal compared to the bearings with only PEEK resin material.

The hybrid PEEK bearings have the following features compared to conventional PTFE resin wrapped bushings:

**[Features]**

**Compared to conventional products (PTFE resin wrapped bushing)**

(1) Friction coefficient: 2/3, wear: 1/3
(2) Heat resistance: more than 5 times

4. Sintered metal products

NTN Powder Metal Corporation works on high functionality of conventional oil-impregnated sintered bearings and develops high-strength machine parts mainly for automotive applications. In the automotive applications, sintered products are increasingly used as a part of the component cost reduction, which accounts for approximately 60% of the sintering market or approximately 9.2 kg per vehicle. The following is the introduction of high-strength sintered materials and various types of sintered bearing products developed for this growing market:

(1) High-strength sintered materials

Sintered machine parts for automotive applications include engines, drive components, and in-vehicle oil pumps and starter motors. Fig. 9 shows an example of sintered gears. In addition, Fig. 10 shows the results from a comparison test of ring compressive fatigue strength of high-strength sintered materials. The fatigue strength of the developed products is about 2.3 times that of the conventional products. The sintered machine parts require not only high-strength but also support for high precision and the ability for complex shaping. Additionally, we are optimizing material composition, manufacturing method, and thermal processing to expand applications starting from replacement of cold forging materials.

**[Features]**

(1) True density ratio: achievement of 96%
(2) Fatigue strength: 2.3 times compared to the conventional products
(3) Young’s modulus: achievement of 180 GPa

Fig. 9 High strength sintered gear
(2) Multi-layer sintered oil-impregnated bearings

With increased infrastructure development in the world including emerging markets, demand for construction machines, such as hydraulic shovels, is also increasing. For joints of these hydraulic shovels, use of sintered oil-impregnated bearings is increasing for longer oiling intervals. Higher strength is also required due to severe operating conditions. Conventionally, oil content is secured in low density to prolong oiling intervals while strength and hardness are improved by thermal processing, then dimensional accuracy is achieved by machining the bearings.

The multi-layer sintered oil-impregnated bearings shown in Fig. 11 have two types of powders with different properties molded simultaneously into one piece so that the inner layer has sliding and wear resistant properties while the outer layer has a high strength property. This process can eliminate the need for thermal processing such as carburized hardening and the machining process to achieve a significant reduction of the manufacturing workload.

(3) Corrosion resistant sintered bearings

Bearings for valves in fuel pumps and exhaust gas recirculation (EGR) systems require high corrosion resistance as they are in contact with fuel, etc. The typical material for this is cupronickel-based materials. However, this material contains a rare metal, nickel, with the requirement for high corrosion resistant bearings without rare metal increasing.

NTN has focused on aluminum bronze which exhibits good corrosion resistance resulting in corrosion resistant bearings with better corrosion resistance and sliding property than cupronickel-based sintered bearings.

Fig. 13 shows an example of bearings for a fuel pump.

[Features]
(1) Corrosion resistance equivalent or superior to cupronickel-based material
(2) Improved corrosion resistance without using rare metal
(3) Significant improvement of wear resistance over cupronickel based material

Table 3 shows the test results of corrosion resistance against organic acid and sulfur. The test piece was
Table 3 Result of anti-corrosion examination

<table>
<thead>
<tr>
<th></th>
<th>Weight change rate %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developed material</td>
<td>Cupronickel based material</td>
</tr>
<tr>
<td>(1) Corrosion resistance test against organic acid</td>
<td>0.14</td>
</tr>
<tr>
<td>(2) Corrosion resistance test against sulfur</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Fig. 13 Sintered bearing for fuel pump

Fig. 14 Comparison of features various core material

immersed in test fluid at the set temperature and time and the variation was calculated from the weight difference before and after test.

<Test condition>

(1) Corrosion resistance test against organic acid
- Test fluid: Organic acid concentration 2%
- Temperature: 50˚C
- Test time: 100 hours

(2) Corrosion resistance test against sulfur
- Test fluid: Gasoline with 300 ppm of sulfur
- Temperature: 80˚C
- Test time: 300 hours

The comparison between the newly developed material and cupronickel based material revealed favorable results, with an equivalent friction coefficient and the specific wear rate approximately 1/10 of the cupronickel based material.

5. Magnetic material products

Nippon Kagaku Yakin Co., Ltd. develops and promotes magnetic material products aiming at the converting mechanical components into functional components. 6)

In this article, we are introducing products for growing the market, particularly by applying its unique technologies.

(1) Reactors for automobiles 7)

The motor drive of the recent hybrid vehicles use dedicated batteries. These vehicles have achieved drive performance equivalent to fuel-driven engines in acceleration/deceleration, which requires step-up (amplification) of the dedicated battery output voltage.

Therefore, step-up reactors are used for the system circuit components, which should support large current/high frequency as well as have a compact size for reducing electric cost. The current hybrid vehicles use Fe-Si (ferrite-silicon alloy powder) with the compression manufacturing method. In addition, for larger current to be applied with higher EV output, Fe (pure iron powder) products with high saturation magnetic flux density manufactured using the compression method are being considered. However, these materials have large iron loss with large heat generation and the step-up reactor tends to become larger in order to avoid this.

Fig. 14 shows the performance comparison of different core material for step-up reactors. The Fe-Si and Fe products made by the above mentioned compression method exhibit large iron loss. In comparison, the amorphous products by Nippon Kagaku Yakin Co., Ltd. have smaller iron loss and can be manufactured by injection and compression molding.

The newly developed “hybrid amorphous core”, in particular, is a combination of injection amorphous core and compression amorphous core. Fig. 15 shows the structure of hybrid amorphous core. Compression...
amorphous with small iron loss is used for the area of electric-magnetic conversion for lower heat generation and injection amorphous with superior shaping flexibility is used for the magnetic conduit for retransmitting the converted magnet to the coil. Fig. 16 shows an analytical example of heat generation of the hybrid core, which indicates appropriate placement of the respective cores. In addition, Table 4 shows a comparison of hybrid core performance against injection and compression amorphous cores, respectively. The hybrid core exhibited favorable results in any property enabling manufacturing of pod-shaped core, which is difficult with compression amorphous core.

**[Features]**

1. Can be used in applications where large current or high frequency is required
2. Compact and low heat generation by composite structure
3. Higher degree of freedom for reactor shape design by injection molding

![Fig. 16 Temperature distribution analysis of hybrid core](image)

Table 4 Comparison of features various reactor core

<table>
<thead>
<tr>
<th></th>
<th>Single core coil (conventional product)</th>
<th>Hybrid core coil (newly developed product)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression core</td>
<td>△ (large press required)</td>
<td>○ (DC bias: good)</td>
</tr>
<tr>
<td>Injection core</td>
<td>△ (large press required)</td>
<td>○ (DC bias: good)</td>
</tr>
<tr>
<td>For large current</td>
<td>△ (large press required)</td>
<td>○ (DC bias: good)</td>
</tr>
<tr>
<td>For high frequency</td>
<td>△ (large press required)</td>
<td>○ (DC bias: good)</td>
</tr>
<tr>
<td>Compact</td>
<td>△ (Permeability: high)</td>
<td>○ (Permeability: low)</td>
</tr>
<tr>
<td>Heat suppressed</td>
<td>△ (Permeability: high)</td>
<td>○ (Permeability: low)</td>
</tr>
<tr>
<td>Flexible shaping</td>
<td>△ (CNC press required)</td>
<td>○ (Injection molding allowed)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>○ (Injection molding allowed)</td>
</tr>
</tbody>
</table>

(2) Dual track magnetic encoder

Industrial machine robotics require high positioning accuracy and use high-resolution absolute angle sensors which requires a highly accurate encoder.

NTN is introducing our newly developed dual track magnetic encoder. Fig. 17 shows the structure of this newly developed product. Hard magnetic material is injected on the core metal of compressed ferrous soft magnetic material. This diagram shows an axial type dual track encoder with inner and outer ring patterns of a different number of accurately magnetized poles. The following are the features of the developed product:

**[Features]**

1. Supports opposite angle detection
2. Angle accuracy: ±0.2˚
3. Supports hollow structure

In addition, Fig. 18 shows an absolute angle measurement method using this developed dual track magnetic encoder. Two sensors facing inside and outside magnetized rings, respectively, detect the signals. The absolute angle can be accurately measured by calculating the relative displacement of the patterns from the magnetic sensor signals, using a principle called caliper or Vernier principle.

![Fig. 17 Structure of dual-track magnetic encoder](image)

![Fig. 18 Absolute angle measurement system](image)
(3) Choke coil for MRI

The MRI shown in Fig. 19 is a medical device used to provide images of sections of the human body using large magnetic energy. The choke coil integrated in this device is an electronic component to generate large current for creating a gradient magnetic field during testing.

Fig. 20 shows the components used for the developed choke coils. The coil, covered by an insulating case, is incorporated in the injection amorphous core to make the choke coil shown in Fig. 21.

Fig. 22 shows the inductance deviation rate (DC bias characteristic), which serves as a measure of the magnetic field generation capability when applied current is swept for amorphous soft magnetic material. In addition, Fig. 23 shows the frequency response of the inductance when weak current is applied. From these properties, the following features can be pointed out and this choke coil is suitable for this application which requires large current and stable high-frequency response characteristics:

[Features]
(i) Inductance deviation rate is small even when high current is applied compared to the conventional ferrite and Fe-6.5Si.
(ii) Change rate of inductance in the high frequency range is smaller than ferrite.

This is used in this developed product and the generally-used ferrite/iron-silicon (Fe-6.5Si) soft magnetic material.

Fig. 19 Medical magnetic resonance imaging

Fig. 20 Parts of choke coil

Fig. 21 Choke coil for MRI power supply

Fig. 22 DC bias characteristics

Fig. 23 Frequency characteristics
6. Conclusion

In this article, new products with composite materials for growing markets are mainly introduced.

With increased fuel efficiency and use of electric drive components in automobiles, being lightweight is a focal point in the development of components and composite material products.

In addition, NTN is also proposing new products to contribute to the development of our customers in the broad field of industrial machines, including medical devices, food equipment, robotics, etc.

NTN is poised to actively develop products by integrating a wide range of materials and technologies in response to the trend of the consistently growing markets and contributing to these markets.

References
2) Takuya Ishii, Yoshihide Himeno: Functional Improvement of Resin Sliding Bearing Through the Combination with Metal, Journal of the Japan Society of Polymer Processing, 25 (2), 73, 2013