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Tribological Properties of PTFE Filled Plants-Derived Semi-Aromatic Polyamide (PA10T) and GF Reinforced PTFE/PA10T Composites

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Abstract. For the purpose of developing the new engineering materials such as structural materials and tribomaterials based on plants-derived polymers, the tribological properties of polytetrafluoroethylene (PTFE) filled plants-derived semi-aromatic polyamide 10T (PA10T) composites and glass fiber (GF) reinforced PTFE/PA10T composites were investigated. PA10T is a kind of polyphthalamide (PPA, semi-aromatic polyamide) and biomass polymer made from plants-derived decamethylenediamine and coal-derived terephthalic acid. PTFE/PA10T and GF/PA10T/PTFE composites were melt-mixed by a twin screw extruder and injection-molded. Their mechanical properties such as tensile, Izod impact, and tribological properties were evaluated. Tribological properties were measured by a ring-on-plate type sliding wear tester under dry condition. Tribological properties of PA10T such as frictional coefficient, specific wear rate and limiting pv value improved with the addition of PTFE, although the mechanical properties such as tensile strength and tensile modulus decreased with PTFE. On the other hand, the frictional coefficient and specific wear rate of GF/PA10T/PTFE composites were higher than those of PTFE/PA10T composites, however limiting *pv* value and mechanical properties improved significantly with the filling of GF. It follows from these results that it may be possible to develop the new tribomaterials based on plants-derived polymer composites with sufficient balances between mechanical and tribological properties.

Keywords: Plants-derive, Polyamide 10T, Semi-aromatic polyamide, Polymer composites, Tribological properties
PACS: 81.05Qk, 81.40.Pq

INTRODUCTION

Polyamide (PA) has excellent characteristics such as good mechanical properties, high heat resistance and ease of processing. However, PA shows high frictional coefficient in dry sliding conditions and is seldom used alone [1, 2]. Normally, it is filled with solid lubricants, fillers and/or fibers and is also blended with other polymers. Many studies have been done on the tribological properties of PA composites [3]. In particular, these studies focused on the tribology of polytetrafluoroethylene (PTFE) filled PA composites (PTFE/PA) [4, 5]. However, there are still a number of problems that need to be solved. Meanwhile, semi-aromatic polyamide, which is a kind of polyphthalamide polymers (PPA), has attracted considerable interest in mechanical sliding parts field because PPA has the excellent characteristics such as high heat resistance, high mechanical strength and chemical resistance. However, in our knowledge, little study has done to investigate the tribological properties of PTFE filled PPA composites [6].

On the other hand, the concern over biopolymers, which are plants-derived ones, has risen in recent years in order to solve the various environmental problems. In our previous studies, we conducted the studies on the mechanical and tribological properties of biomass composites based on plants-derived biopolymers such as polylactic acid and polyamide1010 [7, 8]. However, sufficient performances applicable as engineering materials have not been obtained yet. Recently, polyamide 10T (PA10T), which is a kind of PPA, has much attracted attention because this is a biopolymer made from plants-derived castor oil. The purpose of this study is to develop the new high performance tribomaterials based on plants-derived materials. The experimental results of tribological properties of polytetrafluoroethylene (PTFE) filled plants-derived semi-aromatic polyamide 10T (PA10T) composites and glass fiber (GF) reinforced PTFE/PA10T composites are presented in this paper.

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Experimental

The materials used in this study were polytetrafluoroethylene (PTFE) filled plants-derived semi-aromatic polyamide (PA10T) composites and glass fiber (GF) reinforced PTFE/PA10T composites. PA10T (Vestamid HT plus M3000, Daicel Evonik Ltd., Japan) was used as the matrix polymer. PTFE (initial particle size d=14μm, molecular weight M=1,900 x 10^3 and sintered type, Kitamura Ltd., Japan) were used as the solid lubricants, and its volume fraction was fixed on 20wt.%. Glass fiber (GF, CSF-3PE, diameter d=13μm and initial length L=3mm, Nitto Boseki Co., Ltd., Japan) was used as the reinforcement and its volume fraction was fixed on 20vol.%.

GF and PA10T were dried in a vacuum oven at 90^{o}C for 4h, and PTFE was cooled in refrigerator at 5^{o}C for 2h. These materials were dry blended in the small stainless bottle using handheld electric mixer and subsequently melt mixed at 85rpm and 310^{o}C on a twin screw extruder (TEX-30, Japan Steel Works, Ltd., Japan). After mixing, extruded strands of PTFE/PA10T and GF/PA10T/PTFE composites were cut in about 5mm by pelletizer, and were dried again at 90^{o}C for 4h in vacuum oven. Various shaped samples for mechanical and tribological properties testing were injection molded (NS20-A, Nissei Plastic Industrial, Japan). The molding conditions were as follows: cylinder temperatures of 310^{o}C, mold (cavity) temperature of 150^{o}C and the injection rate of 6cm^3/s. To keep the drying conditions of specimens for all measurements, they were kept in accordance with JIS K 6920-2 for at least 24h at 23^{o}C in desiccators after injection molding.

Tensile and triborogical properties were evaluated. Tensile tests were carried out with dog-bone shaped samples (12mm x 60mm x 3mm) on Toyo Seiki testing machine V-10 at room temperature in accordance with JIS K 7161, and at the cross-head speed of 50 mm/min. Tribological properties were measured by a ring-on-plate type sliding wear tester (EFM-3-EN, Orientech Co., Japan) under dry condition. A carbon steel (S45C) ring with the surface finished by No.800 polishing paper was used as a counterpiece. Two types of tribological testing were carried out by 1) constant normal load and sliding speed testing at the sliding speed of 0.5m/sec, sliding distance 3000m and normal load of 100N and 2) limiting *pv* value testing by the step load method at the sliding speed of 0.5m/sec and step load of 50N/5min. The surface of samples fractured cryogenically in liquid nitrogen was observed using scanning electron microscope (SEM, VE-8800S, Keyence Co. and JSM-6360LA, JEOL Ltd., Japan) for understanding the internal structure of PTFE/PA10T and GF/PA10T/PTFE composites.

RESULTS AND DISCUSSION

First, the tensile properties which is the basic variable in mechanical properties, of PTFE filled plants-derived semi-aromatic polyamide 10T (PTFE/PA10T) composites and GF filled PTFE/PA10T (GF/PA10T/PTFE) composites are discussed. Fig.1 shows the relationship between tensile strength σ_t and tensile modulus E_t of various composites. The tensile properties such as σ_t and E_t of GF/PA10T are twice as high as that of pure PA10T (100%). Although tensile properties, especially tensile strength of neat PA10T remarkably decrease with the addition of PTFE, those of GF/PA10T composites slightly decrease with the addition of PTFE. In the case of PA10T composites, the effect of filling GF on the tensile properties is higher than that of the addition of PTFE.

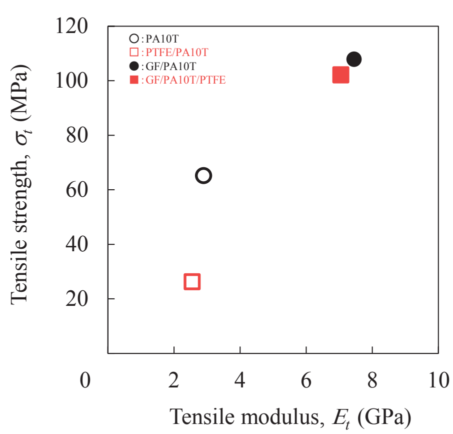
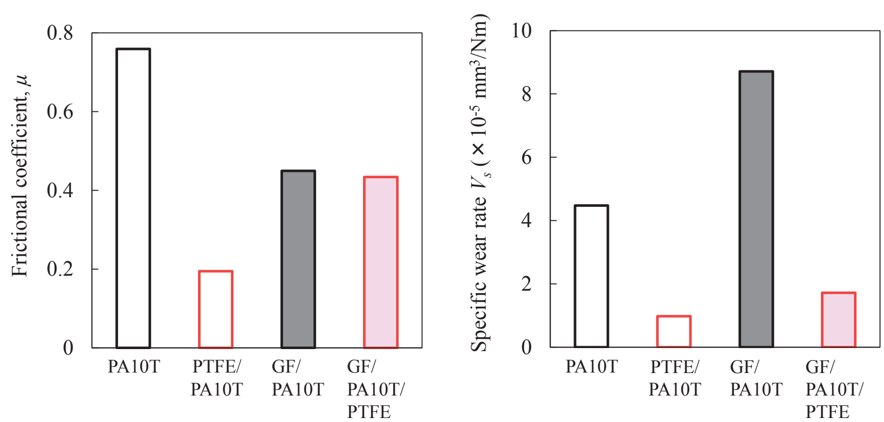


FIGURE 1. Tensile properties of PTFE/PA10T and GF/PA10T/PTFE composites

The tribological properties of PTFE/PA10T and GF/PA10T/PTFE composites by constant normal load and sliding speed testing using a ring-on-plate type sliding wear tester are discussed. Fig.2 (a) shows the average frictional coefficient μ of various PA10T composites. Although μ of PTFE/PA10T is a quarter of pure PA10T, those of GF/PA10T/PTFE and GF/PA10T are a half of pure PA10T. The effect of the addition of PTFE on the μ of GF/PA10T composites has the same tendency as that of tensile properties. On the contrary, the specific wear rate V_s shows different behavior according to the type of fillers. Fig.2 (b) shows V_s of various PA10T composites. The effect of addition of PTFE on the V_s of PA10T and GF/PA10T composites remarkably decreases V_s although the filling of GF increases V_s of PA10T. In particular, PTFE has a good improvement effect for the tribological properties of PA10T and GF/PA10T composites. These results may be attributed to the change in the mode of wear mechanism by the addition of GF and PTFE. Because the triborogical behavior of polymer composites are strongly influenced by their ability to form a transfer film on the counterface, it is essential to observe this factor for understanding the mechanisms of tribological behavior [9].

Fig.3 presents SEM photographs on the surface of metallic counterface (S45C) after sliding wear testing against neat PA10T, PTFE/PA10T, GF/PA10T and GF/PTFE/PA10T composites. The morphology after sliding wear test of PA10T Fig.3 (a) shows thick transfer films surface overall. On the other hand, that of PTFE/PA10T composites Fig.3 (b) show thin transfer films and small wear debris. This is the effect of the addition of PTFE on the triborogical properties of the polymer composites. To the contrary, the morphology of GF/PA10T Fig.3 (c) shows big and thick wear debris on the counterface, which contains many fine fractured GF. On the other hand, that of GF/PA10T/PTFE Fig.3 (d) is formed with a film of an intermediate thickness between PA10T and PTFE/PA10T composites. These differences in formation of transfer films on the counterface are considered to induce the change of the tribological properties of PA10T composites. This is because the frictional surface changes with progressing the testing. Specifically, this changes between the transfer film on the counterface and the polymer composites from between the initial metallic counterface and the polymer composites. However, it is necessary to further clarify the above mechanisms to carry out detailed observations of the counterface, worn surfaces and wear debris of various PA10T composites in future work. The SEM photographs of them after sliding wear testing will be reported at the conference presentation.



(a) Frictional coefficient (b) Specific wear rate

FIGURE 2. Tribological properties of PA10T composites

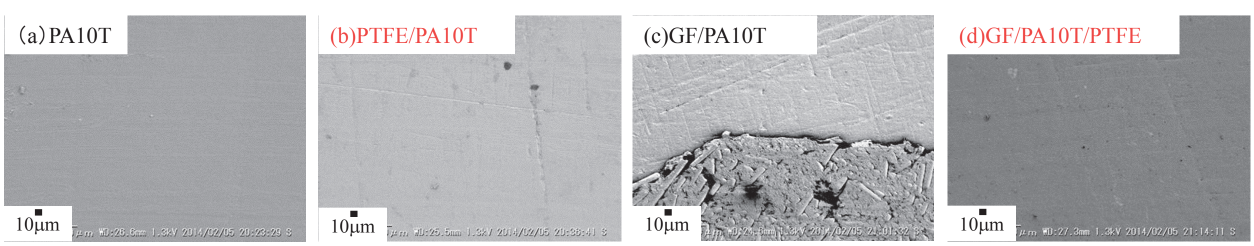


FIGURE 3. SEM microphotographs of counterface of PA10T and PA10T composites

The limiting *pv* value testing results by the step load method of PA10T composites, which is more severe than constant load and speed testing are discussed. Fig.4 shows the limiting *pv* value of various PA10T composites. The limiting *pv* values increase with filling PTFE and GF. In particular, that of GF/PA10T/PTFE ternary composites filled with both GF and PTFE is the highest among various PA10T composites. This is considered to be due to the fact that both triborogical and mechanical properties are improved by the addition of GF and PTFE.

These mechanical and tribological properties of plants-derived polymer (PA10T) composites shown above have the same tendencies as those of ordinary petroleum-derived engineering plastic composites (PA66 and PA6T) [9-11]. It follows from these results that it may be possible to develop the new tribomaterials based on plants-derived polymer composites with sufficient balance between mechanical and tribological properties.

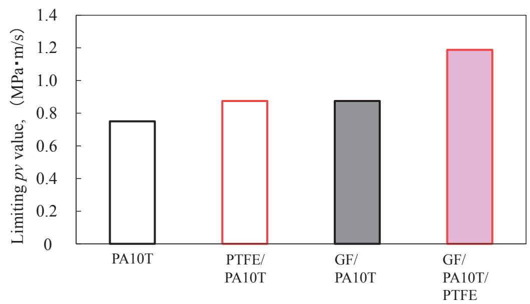


FIGURE 4. Limiting *pv* value of PTFE/PA10T composites

CONCLUSION

The purpose of this study is to develop the new high performance tribomaterials based on plants-derived materials. The tribological properties of polytetrafluoroethylene (PTFE) filled plants-derived semi-aromatic polyamide 10T (PA10T) composites and glass fiber (GF) reinforced PTFE/PA10T composites were investigated experimentally. It was found that the tribological properties of PA10T such as frictional coefficient, specific wear rate and limiting *pv* value improve with the addition of PTFE, although the mechanical properties such as tensile strength and tensile modulus decrease with PTFE. On the other hand, the frictional coefficient and specific wear rate of GF/PA10T/PTFE composites were higher than those of PTFE/PA10T composites, however limiting *pv* value and mechanical properties improved significantly with the filling of GF. It follows from these results that it may be possible to develop the new tribomaterials based on plants-derived polymer composites with sufficient balances between mechanical and triborogical properties.

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