doi:10.20944/preprints201701.0112.v1

Article

Effects of Potassium Titanate Whisker or Glass Fiber on Tribological and Mechanical Properties of PTFE/PEEK Blend

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Abstract: In this study, 10%PTFE/PEEK blend were modified by potassium titanate whisker (PTW) and chopped glass fiber (GF), respectively. The blends were prepared by three-screw extruder. Through the investigation of thermal stability, tribological properties, mechanical properties and rheological behavior, the effects of reinforcing agents were determined. The results illustrated that the mechanical properties of 10%PTFE/PEEK blend can be dramatically improved by adding reinforcing agent of PTW or GF, and the reinforcing effect of GF was especially obvious. As for tribological properties, 1% addition was the best proportion. The friction coefficient and wear rate of the blend with 1% PTW were 0.283 and 4.97×10^{-6} $mm^3/N \cdot m$, which decreased by 7.2% and 21% compared with those of the blend without reinforcing agent.

Keywords: PEEK; blends; thermal stability; tribological properties; mechanical properties

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1. Introduction

Polyether ether ketone (PEEK) is a kind of thermoplastic aromatic polymer material, which is also one of the most important special engineering plastics in poly (aryl ether ketone) (PAEK) family [1,2]. PEEK has a lot of excellent properties, such as high temperature resistance, dimensional stability, biocompatibility and so on [1,3,4]. Consequently, PEEK materials are widely used in aerospace, automotive, medical and other fields [5,6].

In recent years, researchers have found that PEEK material still had some limitations in quite a few extreme conditions. In metallurgy, automotive, aerospace and precision instruments and other fields, quality wear caused by friction effect not only shortens the mechanical life, but also limits the design and use of equipment [7]. Pure PEEK resin is difficult to meet the requirements. Therefore, the modification of PEEK has been the focus of polymer materials workers [3][8]. Polymer blending is a powerful route toward materials exhibiting properties and cost performances superior to those of their individual components [9,10]. Modification cannot only reduce the cost of PEEK products, but also can effectively improve performance, and further expand its application areas.

Since glass fiber (GF), carbon fiber (CF), and calcium carbonate whisker ($CaCO_3$) and potassium titanate whisker (PTW) have good affinity for various engineering materials and excellent modification effects, they can be used as filler to modify PEEK [1-3].

Ma et al [4]prepared short CF and potassium titanate-reinforced PEEK composites by extrusion and injection molding. Under the condition of high short CF content, the composites showed excellent tribological heat, but the wear increased under high load.

Sharma et al [5] modified CF by plasma to improve the mechanical and tribological properties of the composites. When CF was not treated by plasma, the friction coefficient of CF / PEEK was 0.12~0.21, and that of CF/PEEK composites decreased by 5% after plasma treatment.

Burris et al [6]prepared a PEEK filled PTFE composite with low friction and ultra-low wear. The wear rate of the composites for each test sample was less than that of unfilled PTFE and PEEK. For a 32 wt% PEEK filled sample, a minimum wear rate of $K = 2 \times 10^{-9} mm^3/N{\cdot}m$ was achieved.

In this paper, Polytetrafluoroethylene (PTFE), as organic lubricant material [1] was added into PEEK. The addition of one-component PTFE to PEEK did not meet the requirements for mechanical properties in practical applications [2,3]. Consequently, 10%PTFE/PEEK blend were modified respectively by potassium titanate whisker (PTW) and chopped glass fiber (GF). The effects of reinforcing agents in PTFE/PEEK blend were studied by adjusting the additive amount of PTW or GF. We hope to improve the mechanical properties on the basis of keeping its great antifriction and wear resistance, and obtain the blending materials which can meet the actual industrial production and application demands both in tribological and comprehensive mechanical properties [4].

2. Materials and Methods

2.1 Materials

Amorphous PEEK (T_g=151°C) powder was purchased from Changchun Jilin University SEP Co., Ltd (China). PTFE (particle size was 12.8 μm) was purchased from Solvay S.A. Short-chopped glass fiber (W/D ratio = 1: 1) was purchased from Nittobo Co., Ltd (China). Potassium titanate whiskers ($K_2O{\cdot}nTiO_2$, n=6) were purchased from Shanghai Jiachen New Material Technology Co., Ltd (China).

2.2 Sample Preparation

PEEK powder, PTFE powder and GF or PTW were first pre-mixed in a high-speed mixer (HSR-800, Shandong Huanxin Co., Ltd) with a speed of 18 r/min for 15 min. The mixed powder was dried in an oven at 120°C for 8 h before extrusion. Content of PTFE was 10 wt%, and the content of PTW or GF was added to be 1 wt%, 3 wt% and 5 wt% of blends. The blends were prepared using three-screw extruder (MEDI-22/40, Guangzhou Putong experimental analysis instrument Co., Ltd.) with a screw speed of 150 r/min at a temperature range of 220°C~240°C. The pellets were obtained by a granulator (Magelis, Guangzhou Putong experimental analysis instrument Co., Ltd.). Pellets were shaped by injection molding machine (TAYU-400, Hangzhou TAYU Machinery Co., Ltd), and rectangular and dumbbell-shaped standard specimens were obtained. Injection molding conditions were as follows: pressure (90~120 MPa), flow rate (70%~90%), barrel temperature (220°C~240°C), mold temperature (30°C~50°C), injection time (10 s), and holding time (70 s).

2.3 Thermal Gravity Analysis (TGA)

The weight loss was measured on a TGA 2050 thermogravimetric analyzer under nitrogen at a flow rate of 100 mL/min with a heating rate of 10°C/min from 100°C to 810°C.

2.4 Heat Deflection Temperature (HDT)

The heat resistance tests were carried out on a Ceast 500 ALOXIDE high temperature thermal deflection temperature/Vicat Apparatus with a heating rate of 2°C/min and a pressure of 1.82 MPa in accordance with GB/T 1634-2004.

2.5 Impregnation Density Testing

The test was performed according to GB/T 1033-86. Selecting cylindrical pin bodies as test samples, and they should be clean, with no cracks, no bubbles and no other defects. The samples were sonicated in an acetone solution for approximately 20 minutes, subsequently placed in an oven to remove residual acetone and water and allowed to cool to room temperature for testing. The density was calculated by Equation (1) as follows:

$$\rho_t = \frac{a \cdot \rho_x}{a-b} \qquad (1)$$

Where ϱ_t was the density (g/cm^3) of the sample at t°C, a was the mass (g) of the sample in air, b was the mass (g) of the sample in the infiltrating solution, ϱ_x was the density of the infiltrating liquid (g/cm^3). The infiltration solution used in this test was deionized water at 23°C.

2.6 Tribological Properties

Tribological properties tests were performed on a friction testing machine (UMT-2, Bruker, Germany) according to ASTM G99-04. The cylindrical pin bodies were standard specimens by injection molding, and the size was ϕ6.3 mm × 18.8 mm. The plate body was 45 # stainless steel with a dimension of ϕ50 mm × 10 mm. Pin body surface and plate surface were polished with 1000 # sandpaper. The friction and wear test was conducted for 2 h and the specimens were subjected to a load of 1 MPa at room temperature. The rotational speed of the plate was 200 r/min and the relative distance between the pin body and the center of the plate body was 20 mm. The product of rotation speed (r/min) and friction perimeter of the plate body (mm/r) was the test distance (mm) passed through pin body per minute.

Initial mass was weighed before the test, and the final mass was recorded after the test, and by subtraction we got the mass loss of the sample, Δ m. The relationship between the mass loss Δ m and the volume loss ΔV was as follows:

$$\Delta V = \frac{\Delta m}{\rho} \times 1000 \qquad (2)$$

Where ΔV was the volume loss (mm^3), Δm was the mass loss (g), and ϱ was the density of the material (g/cm^3). The wear rate was evaluated by the following Equation (3):

$$W_r = \frac{\Delta V}{F_z \cdot L} \qquad (3)$$

Where Fz was the load pressure in vertical direction (N); L was total distance (m) the specimen passed on the plate surface.

2.7 Mechanical Testing

Tensile test and three-point bending test were performed on a Shimadzu AG-1 universal testing machine at room temperature. Depending on GB/T 1040.2-2006, the stretch specimens were dumbbell-shaped with dimension of 75 × 12.5 × 2.0 mm^3. According to GB/T 9341-2008, the bending specimens had a size of 80 × 10 × 4 mm^3 and the cross-thickness ratio was 15. Spans for tensile and bending tests were 20 mm and 60 mm, and the crosshead speeds were 5 and 2 mm/min, respectively.

Impact strength was tested using a charpy impact testing machine (HIT-2492, Chengde Jinjian Detection Equipment Co., Ltd) with a method of GB/T 9341-2000. The impact speed was 2.9 m/s.

The data reported were average values of five samples.

2.8 Scanning Electron Microscope (SEM)

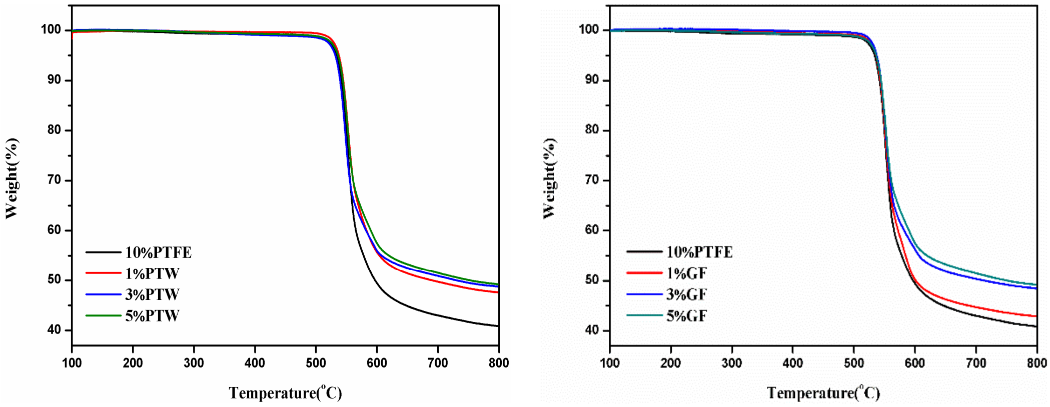
The morphology of wear surfaces and impact fracture surfaces were observed by scanning electron microscope (SEM-450, FEI, Netherlands), operating at a 15 kV accelerating voltage. The surfaces were all sprayed with gold before scanning.

3. Results and Discussion

3.1 Thermal Stability

TGA and HDT results of different blends were presented in Table 1 and Figure 1. From the data in Table 1, T_{d5} and T_{d10} of the blends with addition of GF and other proportions of PTW were higher than those of 10%PTFE/PEEK blend (535.8°C, 542.7°C), except for the blend with 1%PTW (532.2°C, 539.8°C). For both of PTW/PTFE/PEEK and GF/PTFE/PEEK blends, T_{d5} and T_{d10} increased with the increasing content of reinforcing agents, respectively. When the addition amount was 1%, T_{d5} and T_{d10} of the blends added GF were higher than those of PTW system blends. After the amount of reinforcing agent exceeded 1%, the condition was the opposite. The excellent thermal stability of PTW or GF was also reflected in the carbon residue. The values of residual carbon of all blends with reinforcing agent ranged from 42.9% to 49.0% at 800°C, which were higher than that of 10%PTFE/PEEK blend (40.9%). In other words, the incorporation of PTW or GF had a definite impact on the thermal stability of 10%PTFE/PEEK blend and the overall T_{d5} remained above 532°C and T_{d10} remained above 539°C.

Table 1. Thermal Stability of PTW/PTFE/PEEK and GF/PTFE/PEEK blends



Samples	T_{d5}[1]/°C	T_{d10}[2]/°C	R_{800}[3]/%	HDT[4]/°C
10%PTFE	535.8	542.7	40.9	130.1
1%PTW	532.2	539.8	47.6	137.3
3%PTW	540.3	548.2	48.8	140.5
5%PTW	547.3	551.1	49.2	143.3
1%GF	536.6	543.5	42.9	136.5
3%GF	539.6	545.7	48.5	140.4
5%GF	543.3	547.7	49.0	142.6

Figure 1. TGA curves of PTW/PTFE/PEEK and GF/PTFE/PEEK blends.

From Figure 2, the addition of PTW or GF significantly increased the heat deflection temperature of the blends. When the amount of reinforcing agent was 5%, the values both of PTW/PTFE/PEEK and GF/PTFE/PEEK blends were approximately 1.1 times as much as the value of 10%PTFE/PEEK blend. At the same amount of addition, the HDT values of PTW system were slightly higher than those of GF system. PTW can be well wrapped in PTFE/PEEK substrate, which played a supporting role in the skeleton to transfer and disperse stress well [1], and the resin was not easy to lead to the slip of macromolecules, thus increasing the stiffness.

The incorporation of GF increased the difficulty of thermal motion of the molecular chains in the blends system [2]. Only increasing the temperature, the polymer chain segments could move freely again. GF was a factor of skeleton supporting, which hindered the effect of load on material under high temperature. Therefore, addition of PTW or GF can improve the use of material in high temperature conditions, also enhance its resistance to heat and force.

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[1] T_{d5}: 5% weight loss temperature;

[2] T_{d10}: 10% weight loss temperature;

[3] R_{800}: carbon residue at 800°C.

[4] HDT: Heat Deflection Temperature.

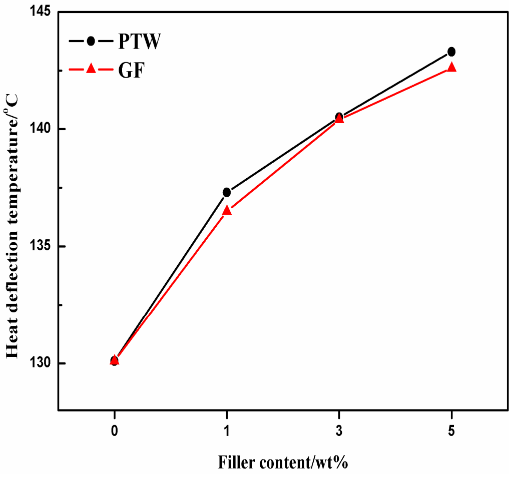


Figure 2. Heat Deflection Temperature of PTW/PTFE/PEEK and GF/PTFE/PEEK blends.

3.2 Tribological Properties

Table 2 listed the friction coefficient, wear amount and wear rate of PTW system and GF system blends. According to Figures 3a and 3b, both friction coefficient and wear rate of PTW/PTFE/PEEK or GF/PTFE/PEEK blends increased slightly with the mass fraction of reinforcing agents, and wear rate was more susceptible. In the aspect of friction coefficient, the value of 10%PTFE/PEEK blend was about 0.305. Only the blends with 1%PTW, 3%PTW and 1%GF were lower than the value and decreased by 7.2%, 5.2% and 0.66%, respectively. As for the wear rate, the value of the blend without reinforcing agent was 6.33×10^{-6}, and only the blends with 1%PTW and 1%GF were less than it, which was 78% and 49% of the former separately. Therefore, within the scope of this study, 1% addition was the best proportion in terms of tribological properties. It should be pointed out that the friction coefficient of PTW series was slightly smaller than that of GF series at the same additive ratio, but the wear rate was just the opposite. The wear rate of PTW series was significantly higher than that of GF series. When the content of PTW was 5%, the wear rate increased by an order of magnitude compared with that of 10%PTFE/PEEK blend, indicating that the wear resistance of GF was better than PTW. However, it is worth mentioning that all of the blending systems with reinforcing agents, regardless of friction coefficient or wear rate were much lower than those of pure PEEK.

Table 2. Tribological Properties of PTW/PTFE/PEEK and GF/PTFE/PEEK blends

Samples	Coefficient of friction	Density (g/cm^3)	Wear amount (mg)	Wear rate ($\times10^{-6}$ $mm^3/N\cdot m$)
PEEK	0.535	1.190	46.5	414.67
10%PTFE	0.305	1.238	0.74	6.33
1%PTW	0.283	1.279	0.60	4.97
3%PTW	0.289	1.284	1.93	15.95
5%PTW	0.310	1.286	3.09	25.49
1%GF	0.303	1.257	0.37	3.09
3%GF	0.343	1.282	0.96	7.93
5%GF	0.348	1.301	1.15	9.36

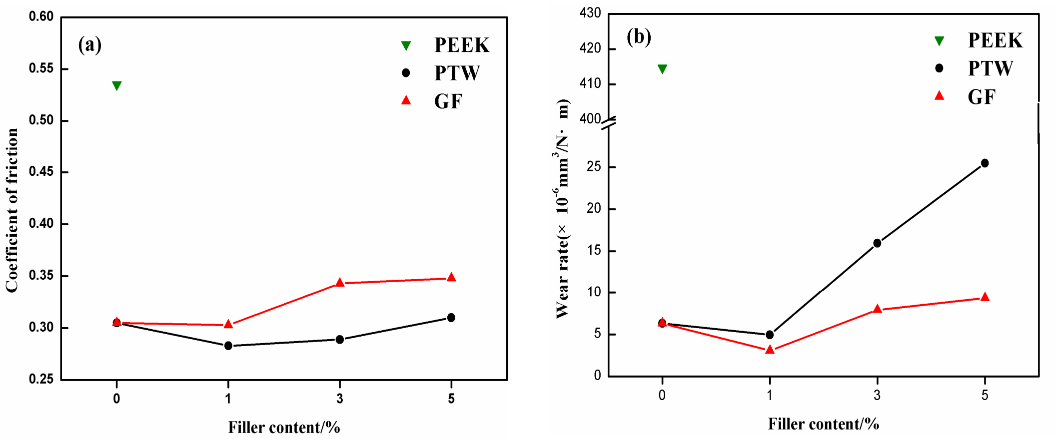


Figure 3. Tribological Properties of PTW/PTFE/PEEK and GF/PTFE/PEEK blends: (a) Coefficient of friction; (b) Wear Rate.

Figure 4a is a curve of friction coefficient versus time of pure PEEK. It can be seen the friction coefficient presented great volatility in the range of 0.460~0.570 with an average of 0.535, and cannot maintain good stability. As the thermal conductivity of PEEK was poor, friction heat was increasing with the sliding distance increased. So the resin surface temperature rose, leading to its partial melting. This change was the main reason for the periodic change of friction coefficient and the increase of frictional resistance. The PEEK used in the study had a lower processing temperature and the contact surface was more susceptible to temperature, thus the friction coefficient cannot keep constant. Irregular ups and downs of friction coefficient indicated that the material was difficult to resist dual effects of temperature and force. The wear rate of pure PEEK was calculated to be 4.15×10^{-4} $mm^3/N \cdot m$.

Figure 4b and Figure 4c are the curves of friction coefficient over time of PTW/PTFE/PEEK blends or GF/PTFE/PEEK blends. As the figure showed, the friction coefficient of the blends increased with the increasing filler content, and the whole condition was stable. In the process of friction, high PTW content made it easy to fall off and form free abrasive grains, which decreased friction stability of the blends. As for GF, on the one hand, the addition of GF destroyed the PTFE transfer film formed on the surface of the friction pair [1]. On the other hand, the fibers tended to form floc-shaped adsorbates in the mixing process, so that the surface roughness of the pin body increased. With the continuous grinding of the friction pair, the pin body was subjected to more severe mechanical kneading and shearing collisions, resulting in sliding difficulty. So the friction coefficient of the blends increased.

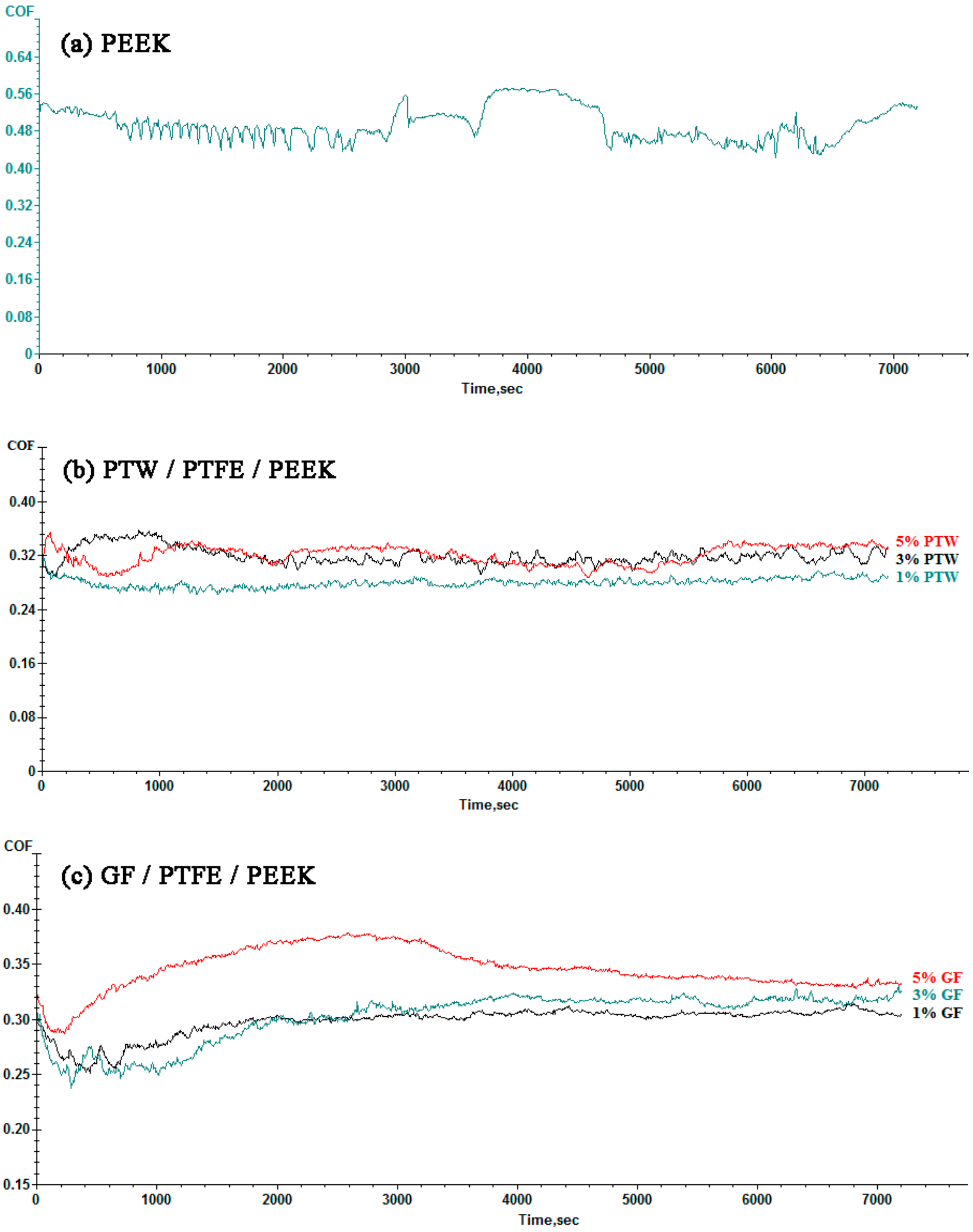
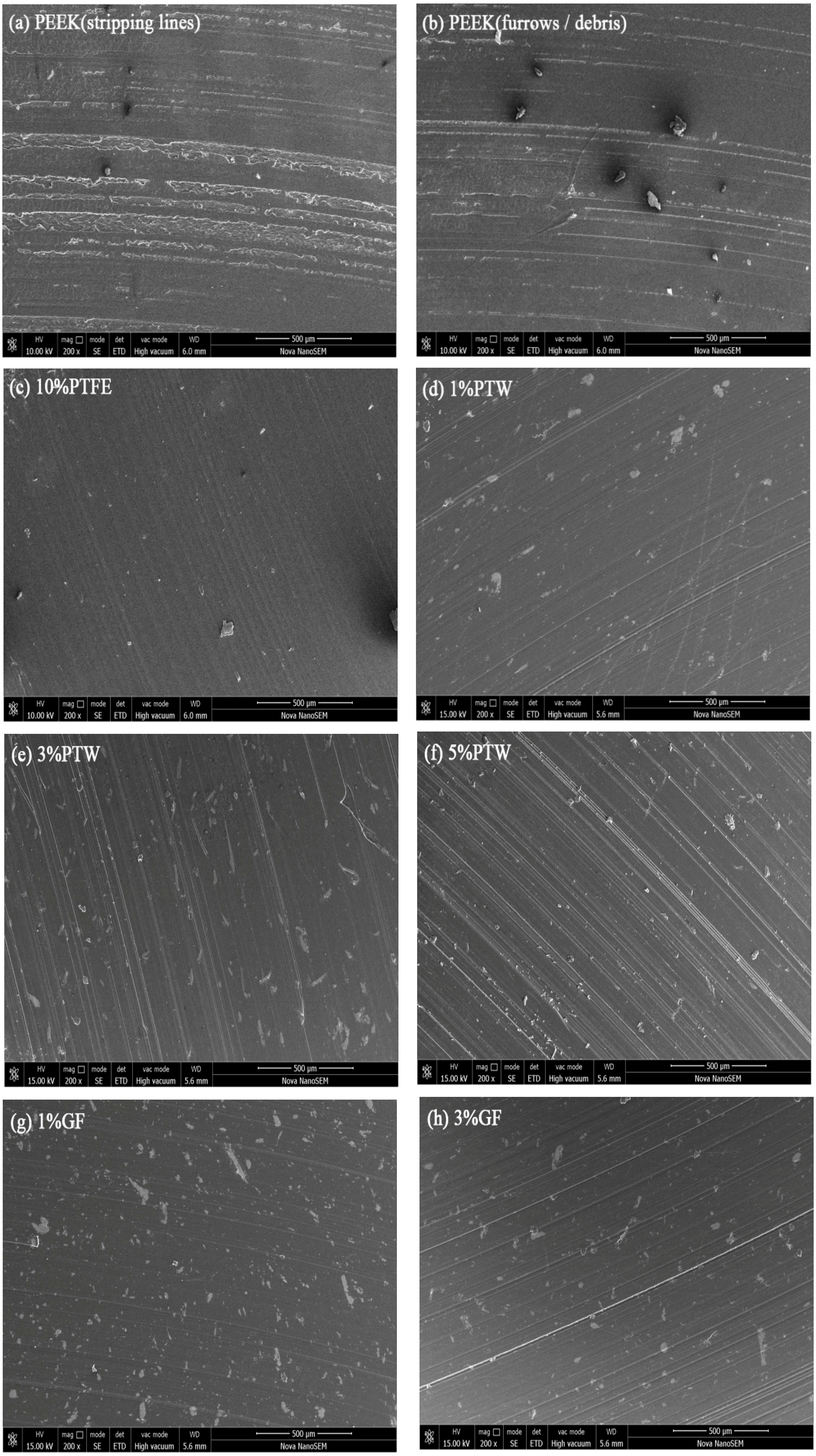


Figure 4. The curves of friction coefficient over time: (a) Pure PEEK; (b) PTW/PTFE/PEEK blends; (c) GF/PTFE/PEEK blends.

Figure 5a and Figure 5b are pure PEEK wear surface SEM photographs. It can be seen that there were many fine and deep trenches along the rubbing direction, which was feature of abrasive wear. While some wider and shallower twisted lines and stripping traces indicated that plastic deformation occurred to PEEK, which was typical morphology of the adhesive wear. From the shape of the wear scar, the size of wear debris and the macroscopical smoothness of the contact surface, it can be seen that most of debris generated during the test was flaky, which accorded with the debris characteristics of polymer in dry sliding friction. After repeated fatigue and cutting effects of the load, the contact surface continued to generate debris. Some directly transferred and adhered to the surface of the friction pair, and some accumulated around the friction path after desorption from the adhesion surface. Some became free abrasive grains and embedded in the friction surface of soft material to form furrows or stripping lines, and sometimes also produced micro-cracks to form pitting (fatigue wear). In summary, the wear of pure PEEK was caused by abrasive wear, adhesive wear and fatigue wear [1,2].

Figure 5c~Figure 5i showed the SEM photographs of 10%PTFE/PEEK, PTW/PTFE/PEEK system and GF/PTFE/PEEK blends. From the figure, it can become quite clear that after the addition of PTFE, wear debris on the wear surface of the blend decreased obviously, and furrows, stripping lines and plastic deformation obviously improved. With the content increase of hard phase reinforcing agents, the thicker strip shape appeared which meant that more fillers contacted with friction pair directly. The increase of filler mass fraction led to its uneven distribution in the matrix, resulting in accumulation. The aggregation of reinforcing agents and PTFE/PEEK matrix weakened, and PTW or GF were prone to fall off during the friction process, which affected the effective adhesion of PTFE transfer film between the pin body and grinding plate [3,4]. As the friction process progressed, wear debris continued to be generated, resulting in the transfer film undergoing repeated destruction-generation processes. The friction coefficient and wear amount of the blends exhibited a slight upward trend. Compared with the PTW, GF can be better embedded in the matrix and the wear rate did not appear dramatic growth.

doi:10.20944/preprints201701.0112.v1



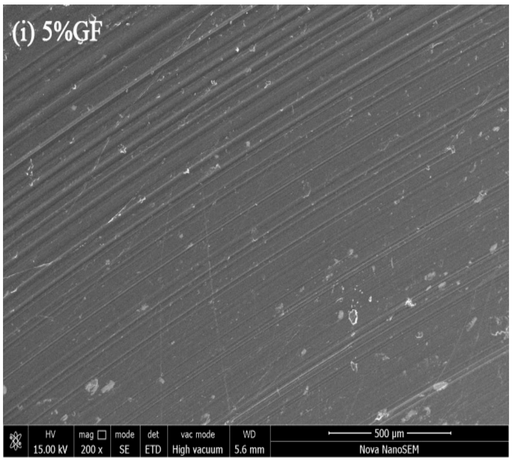


Figure 5. Scanning Electron Microscope Photographs on the Wear Surface：(a) Pure PEEK Stripping Lines; (b) Pure PEEK Furrows/Debris; (c) 10%PTFE/PEEK blend; (d) 1%PTW/PTFE/PEEK blend; (e) 3%PTW/PTFE/PEEK blend; (f) 5%PTW/PTFE/PEEK blend; (g) 1%GF/PTFE/PEEK blend; (h) 3%GF/PTFE/PEEK blend; (i) 5% GF/PTFE/PEEK blend.

3.3 Mechanical Properties

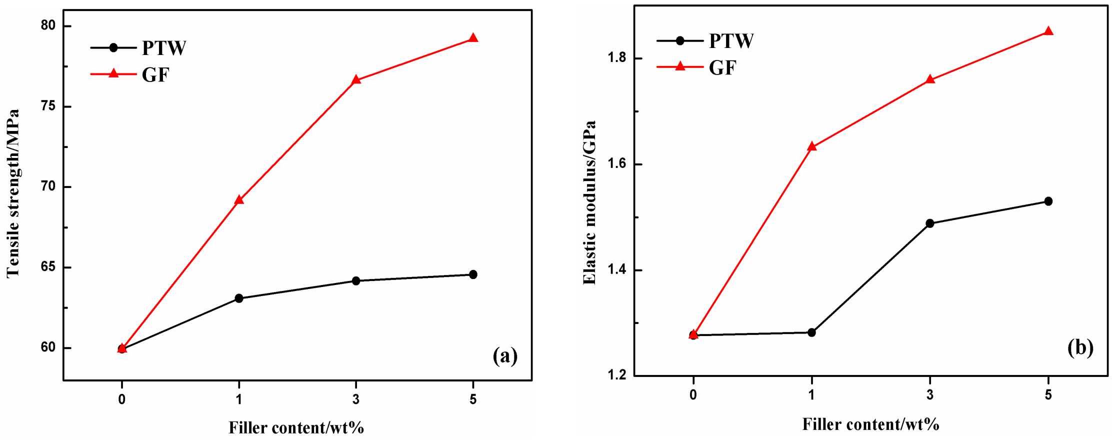
It can be observed in Table 3 and Figure 6 that the mechanical properties of PTFE/PEEK blend were improved by adding PTW or GF. With the increase of reinforcing agent content, the tensile strength and elastic modulus, bending strength and bending modulus of blends were increased, and the reinforcing effect of GF was especially obvious. When adding 5%PTW, the tensile strength and elastic modulus were about 1.1 times and 1.2 times of those of the blend without adding reinforcing agent, respectively. Due to good interfacial adhesion between PTW and PTFE/PEEK matrix, the stress rapidly migrated from matrix to whisker under tensile load, and PTW was subjected to the primary stress. Similarly, when the GF content was 5%, the tensile strength and elastic modulus of the blend were about 1.3 times and 1.4 times as high as those of unmodified blend. Since the glass fiber was well encapsulated by the PTFE/PEEK matrix [27,28], there were numerous fibers in any cross section that could assume and distribute the load. While fiber extraction or fracture needed to impose more load, so the tensile strength of the blends was enhanced. In addition, an increase in the mass fraction of GF also meant an increase in the volume content, which reduced the matrix content between the fibers. The deformation of the matrix in the load direction was restrained and controlled by the fibers, exhibiting a substantial increase in the elastic modulus.

The filling of superior strength reinforcing agents can effectively reduce the crack initiation of local weak bonding under bending stress and prevent the expansion of cracks. As a result, the bending strength and bending modulus of PTW and GF blends increased. It is noteworthy that GF system blends exhibited much better tensile and bending properties than PTW system blends at the same additions, indicating that GF in PTFE/PEEK blend had excellent load-carrying capacity and load-dispersing ability.

With respect to the impact strength, as showed in Figure 6e, the impact strength of PTW and GF system blends reached maximum at the addition of 1%, which was 19.8 $KJ{\cdot}m^{-2}$ and 18.5 $KJ{\cdot}m^{-2}$, respectively. And then the values significantly decreased with the filler mass fraction increased, but not less than 10%PTFE/PEEK blend (12.1 KJ·m^{-2}). The impact properties were mainly associated with the inherent properties of whiskers and matrix, whisker content, geometry, arrangement and interfacial bonding strength [29-31]. The most important of these was interfacial bonding strength, which affected the absorption of impact energy by affecting the fracture mode of the material. The whiskers, on the one hand, bore most of the load near the notch of the specimens and distributed the stress to a larger area. On the other hand, the breaking and pulling out of the whiskers could absorb certain impact energy, so that the impact strength of the blends increased. However, when the amount of reinforcing agents was too large, it was difficult to uniformly disperse in the matrix, and interfacial bonding may also be affected to form large defects. In this case, the reinforcing agent, which originally acted as stress-bearing and stress-dispersing agent, became impurity in the matrix and was more likely to cause the formation and propagation of cracks. So the absorption of energy became smaller, and external load made the material more prone to fracture damage, which was reflected in the impact strength reduction.

Table 3. Mechanical Properties of PTW/PTFE/PEEK or GF/PTFE/PEEK blends

Samples	Tensile strength (MPa)	Elastic modulus (GPa)	Bending strength (MPa)	Bending modulus (GPa)	Impact strength (KJ·m^{-2})
10%PTFE	59.9	1.3	90.2	2.8	12.1
1%PTW	63.1	1.3	91.9	2.9	19.8
3%PTW	64.2	1.5	93.1	2.9	15.2
5%PTW	64.6	1.5	94.2	3.1	13.1
1%GF	69.2	1.6	101.6	3.2	18.5
3%GF	76.6	1.8	114.2	3.6	15.8
5%GF	79.2	1.9	118.3	3.9	15.7



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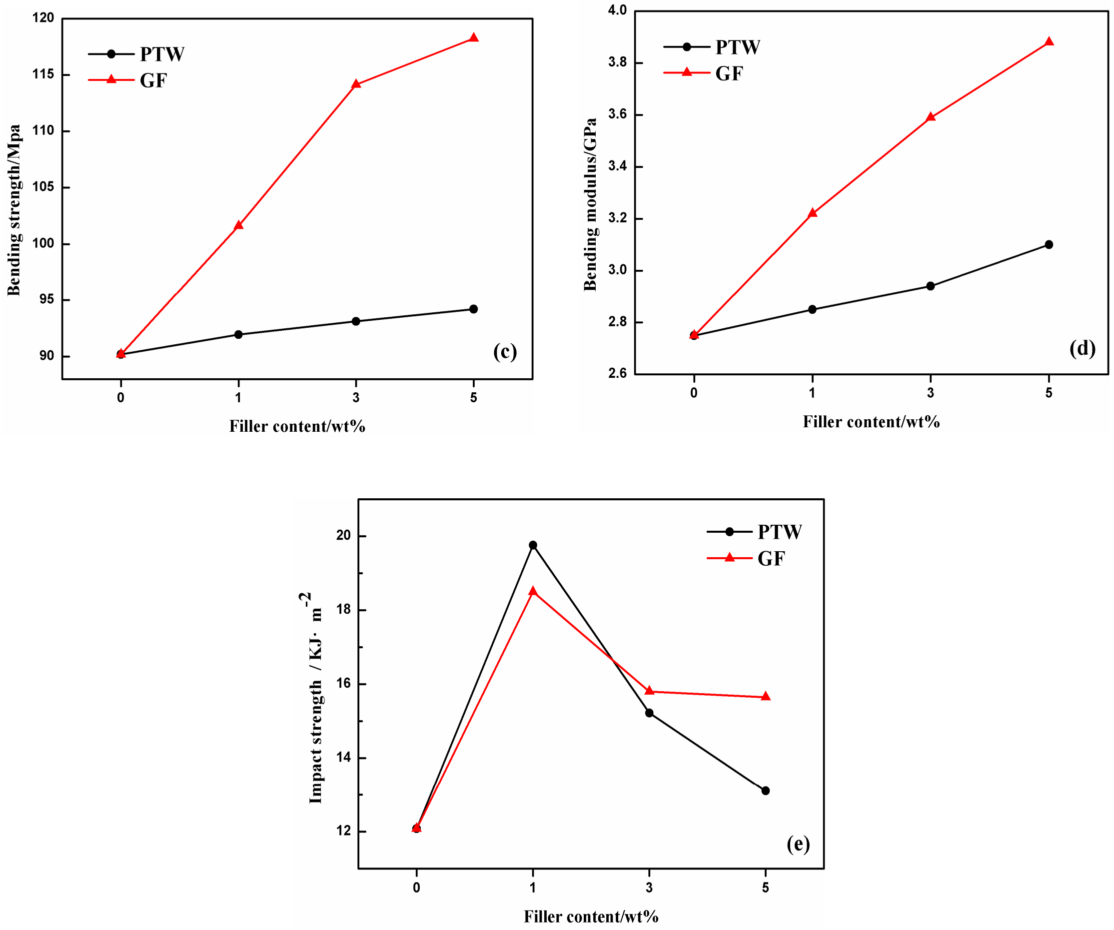
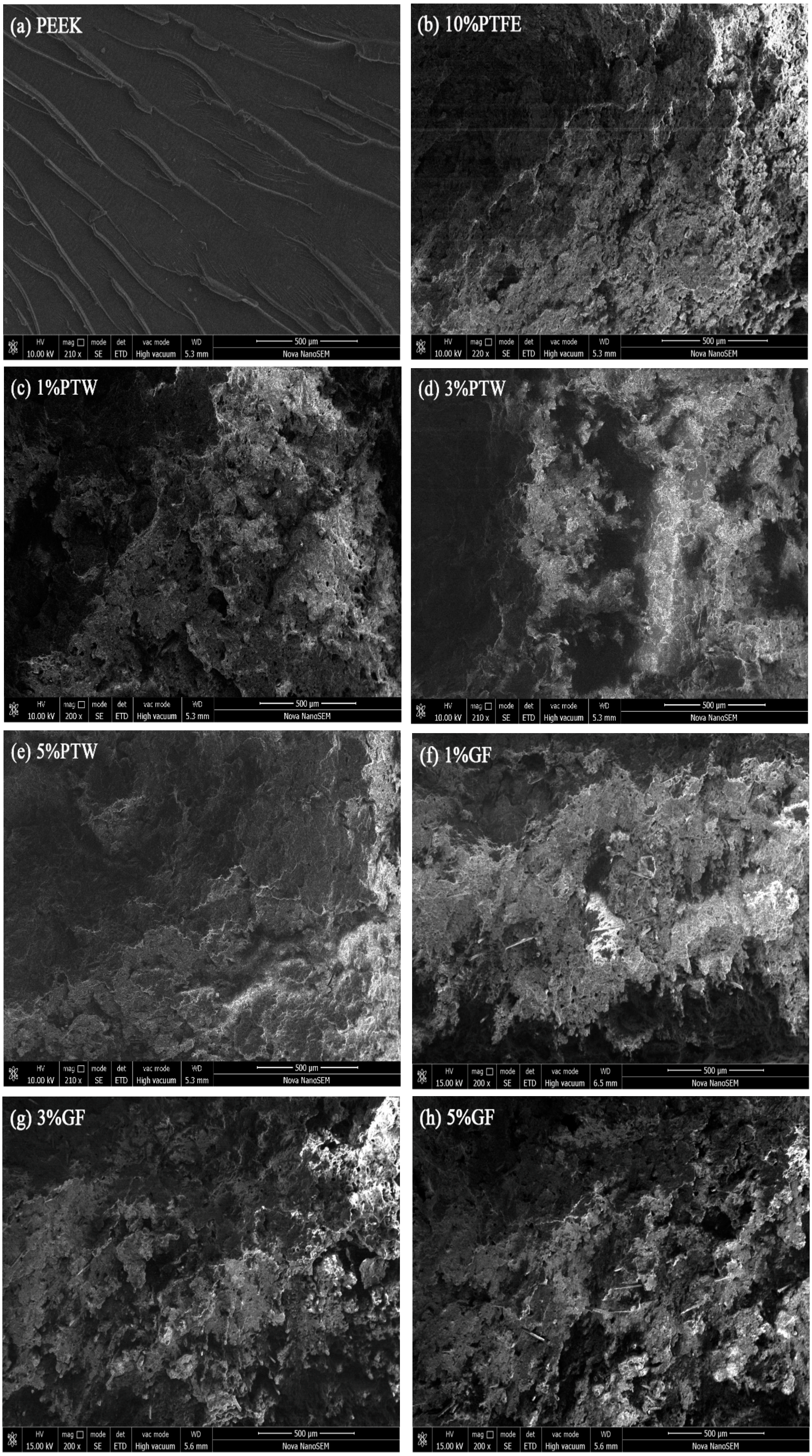


Figure 6. Mechanical Properties of PTW/PTFE/PEEK or GF/PTFE/PEEK blends: (a) Tensile strength; (b) Elastic modulus; (c) Bending strength; (d) Bending modulus; (e) Impact strength.

Figure 7 showed the impact cross section SEM images of PTW/PTFE/PEEK and GF/PTFE/PEEK blends. From figure 7a we can see the impact fracture of pure PEEK was typical brittle fracture [32], showing large radial fracture, and crack development was fast. From Figure 7c~Figure 7e, it can be clearly observed the characteristics of plastic deformation, indicating that the blends had undergone plastic deformation in the process of fracture. Some whiskers can be seen in the matrix, indicating that PTW could still be coated in PTFE/PEEK matrix after the impact fracture, and no obvious whisker debonding [13,33,34].

The effects of the addition of GF on the impact strength were similar to PTW. From the Figure7f~Figure 7h, we can see that the interfaces of the blends were loose and GF remained relatively intact shape without plenty of broken marks. Owing to the brittleness of GF itself, a gradual increase in the amount may lead to its poor adhesion to substrate. In addition, an increased amount meant that the number of fiber ends was increased. Under the action of the impact load, end-induced crack growth could destruct the protective effect of GF, so the impact resistance of the blends was decreased.


(a) PEEK
HV 10.00 kV mag 210 x mode SE det ETD vac mode High vacuum WD 5.3 mm 500 μm Nova NanoSEM
(b) 10%PTFE
HV 10.00 kV mag 220 x mode SE det ETD vac mode High vacuum WD 5.3 mm 500 μm Nova NanoSEM
(c) 1%PTW
HV 10.00 kV mag 200 x mode SE det ETD vac mode High vacuum WD 5.3 mm 500 μm Nova NanoSEM
(d) 3%PTW
HV 10.00 kV mag 210 x mode SE det ETD vac mode High vacuum WD 5.3 mm 500 μm Nova NanoSEM
(e) 5%PTW
HV 10.00 kV mag 210 x mode SE det ETD vac mode High vacuum WD 5.3 mm 500 μm Nova NanoSEM
(f) 1%GF
HV 15.00 kV mag 200 x mode SE det ETD vac mode High vacuum WD 6.5 mm 500 μm Nova NanoSEM
(g) 3%GF
HV 15.00 kV mag 200 x mode SE det ETD vac mode High vacuum WD 5.6 mm 500 μm Nova NanoSEM
(h) 5%GF
HV 15.00 kV mag 200 x mode SE det ETD vac mode High vacuum WD 5.6 mm 500 μm Nova NanoSEM

doi:10.20944/preprints201701.0112.v1

Figure 7. Scanning Electron Microscope Photographs on the impact cross section: (a) Pure PEEK; (b) 10%PTFE/PEEK blend; (c) 1%PTW/PTFE/PEEK blend; (d) 3%PTW/PTFE/PEEK blend; (e) 5%PTW/PTFE/PEEK blend; (f) 1%GF/PTFE/PEEK blend; (g) 3%GF/PTFE/PEEK blend; (h) 5%GF/PTFE/PEEK blend.

4. Conclusions

In this paper, PEEK was used as the resin matrix, and 10% organic lubricant additive of PTFE was added into it. Blend was modified by potassium titanate whisker (PTW) and chopped glass fiber (GF). We have carried out a detailed study on thermal stability, heat resistance, tribological properties, mechanical properties, rheological behavior and so on, and the effects of different types and contents of reinforcing additives on comprehensive properties of the blends were investigated. The following conclusions were obtained:

(1) The incorporation of PTW or GF had a certain impact on the thermal stability of 10%PTFE/PEEK blend and significantly increased the heat deflection temperature. T_{d5} of all blends in the context of this study were above 532°C and T_{d10} were above 539°C. The values of residual carbon of all blends with reinforcing agents ranged from 42.9% to 49.0% at 800°C, which were higher than that of 10%PTFE/PEEK blend (40.9%).

(2) Within the scope of this study, 1% addition was the best proportion in terms of tribological properties. The friction coefficient of PTW series was slightly smaller than that of GF series at the same additive ratio, but the wear rate was just the opposite, indicating that the wear resistance of GF was better than PTW. All blend systems with reinforcing agents, whether friction coefficient or wear rate was much lower than those of pure PEEK.

(3) Mechanical properties of PTFE/PEEK blend were improved dramatically by adding PTW or GF. With the increase of reinforcing agent content, the tensile strength, elastic modulus, bending strength and bending modulus of blends were increased, and the reinforcing effect of GF was especially obvious. The impact strength of PTW and GF system blends reached the maximum at 1% addition.

Acknowledgments: We thank the editors and anonymous reviewers for their valuable comments throughout the review process. The author(s) received no financial support for the research, authorship, and/or publication of this article.

Author Contributions: Xue Teng contributed to the experimental work and wrote the manuscript; Lefei Wen assisted with the experimental work; Yunxia Lv and Wenge Tang assisted with data analyses; Xiaogang Zhao contributed to the concept, design, and revision of the manuscript; Chunhai Chen contributed reagents/materials/analysis tools.

Conflicts of Interest: The authors declare no conflict of interest.

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