High-performance polyimide fiber and its Application in composites

Qiyan GE, Hongqing NIU, Mengying ZHANG, Dezhen WU（武德珍）*
State Key Laboratory of Chemical Resource Engineering, College of Materials Science and Engineering, Beijing University of Chemical Technology(北京化工大学), Beijing 100029, China
Corresponding author: Tel. /fax: +86 10 6442 1693.
E-mail address: wdz@mail.buct.edu.cn (Dezhen Wu).

Abstract: High-performance aromatic polyimide (PI) fibers are considered as one of the most promising engineering materials in the class of polymeric fibers. A serious of PI fibers with different chemical structure and properties have been made by using a continuously manufacturing method from poly (amic acid) solution. High strength and modulus of 3.5GPa and 150GPa have been reached. Compared with PPTA and UHMWPE fibers, PI fibers have excellent mechanical properties, superior chemical and radiation resistance, outstanding thermal-oxidative stabilities. PI fibers were used to reinforce epoxy resins, and the strength and modulus have been improved greatly. The electric permittivity and loss tangent of epoxy composites reinforced by PI fibers are under 3.6 and 0.014 respectively, which is much lower than that reinforced by PPTA fibers. The results show that PI fibers have good potential applications in the fields of aerospace and electronics.
Keywords: Polyimide fibers; Mechanical properties; Composites

Introduction

Aromatic fiber reinforced composite materials have become significantly popular in recent years. The application has considerably become very vast due to its excellent mechanical properties, lighter weight, unique flexibility, corrosion resistant, ease of fabrication, etc., compared to other conventional metallic materials [1-5]. As well-known, polyimide (PI) materials are excellent polymers with good mechanical and dielectric properties, outstanding thermal stability, and superior chemical, irradiation and fire resistances. PI fibers are recognized as one of the important members in the family of aromatic fibers. Over the past half century, tremendous attentions have been paid on the exploration and preparation of high–performance PI fibers. The PI fiber products with high temperature stabilities and lower mechanical properties have been produced and applied to making dedusting bags and protective clothing. Many approaches have been employed to improve the mechanical properties of the PI fibers prepared by the two–step method. Among them, incorporating aromatic heterocyclic units to increase the rigidity of the PI backbones or introducing additional intermolecular associations such as hydrogen bonding and/or chemical cross-linking have been reported to be efficient methods[6-10]. The high-performance polyimide (PI) fibers have been made.

In the present work, the mechanical and thermal properties, the chemical, and radiation resistance of PI fibers were investigated in detail and the comparison with other organic fibers was given. The composites of epoxy reinforced by PI fibers were prepared and the properties were characterized.

Experimental

The PI fibers were provided from Jiangsu Shino New Materials Technology Co., LTD. All the PPTA

Ⅱ and Ⅲ, UHMWPE fibers, and epoxy and PA resins were purchased in the market.
All preparation of composites was followed by some literature and the properties of PI fibers and its composites were evaluated by some standards.

Results and discussion

1. PI fibers and their Properties

The brands and properties of PI fibers produced by Jiangsu Shino New Materials Technology Co., LTD were shown in table 1.

Table 1 The serious PI and their properties

PI	Tensile strength (GPa)	Tensile modulus (GPa)	Elongation at break (%)	Glass transition temperature (℃)	Td5(℃)	LOI	Water absorption (%)
S30	2.8±0.2	110±10	3	≥330	≥550	≥40	≤1.5
S30M	3.0±0.2	140±10	2.5	≥350	≥550	≥40	≤1.5
S35M	3.5±0.2	150±10	2.5	≥350	≥550	≥40	≤1.5

It is can be seen that the PI fibers have excellent mechanical and thermal properties, good fire resistance and lower water absorption, which made them to be applied in composites. A serious of PI fibers with different properties are due to their different chemical structures. The typical structures of PI fibers with good mechanical properties were synthesized from BPDA and PDA, and other monomers which were used to tune the properties and structure.

2. Comparison of PI with other fibers

The mechanical properties of PI-S35M , PPTA Ⅱ, PPTAⅢ and UHMWPE were shown in fig.1. The tensile strength and modulus of PI fiber is higher than PPTA Ⅱ and UHMWPE, but lower than PPTA Ⅲ. Thermal dynamic mechanical behavior of the prepared fibers were measured using a dynamic mechanical analysis (DMA), the glass transition temperature of PI fiber is higher than PPTA Ⅱ and PPTAⅢ because of rigid chemical structures of PI.

The chemical and radiation resistance of PI and PPTA fibers are shown in table 2 and fig.3. The PI fiber has better water, acid and radiation resistance than PPTA fiber.

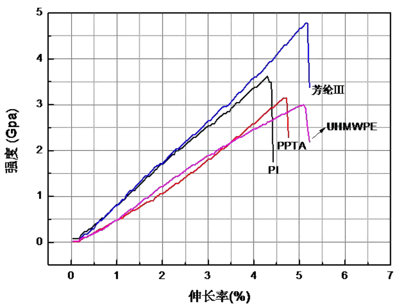

Fig.1 The mechanical properties of 4 fibers

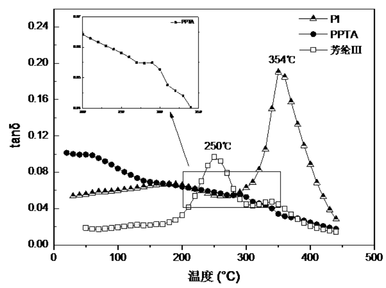

Fig.2 DMA curves of PI and PPTAs

Table 2 Resistance in acid and basic environment of PI and PPTA fibers

Environment	Retention rate of strengthen	
	PI	PPTA
60°C 20wt%NaOH,0.5h	73%	88%
25°C 40wt%H2SO4,200h	Almost 100%	80%
95°C deionized water,20h	Almost 100%	85%

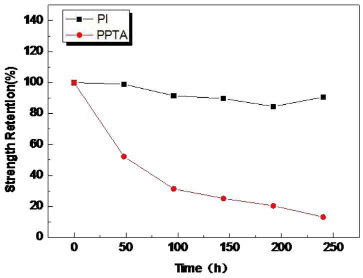

Fig. 3 The radiation resistance of PI and PPTA fibers

3. Epoxy Composites

Surface morphologies of the fibers were studied by SEM. Fig.4 shows that the surface of the PI fibers and PPTAⅢ fibers are relatively rougher than the PPTAⅡ fibers because the PI and PPTAⅢ were produced by wet-spinning methods. The surface roughness of the fibers is attributed to increasing the interfacial interaction with the matrix. Thus, the surface roughness was verified by the results of the interlaminar shear strength (ILSS), which is shown in table 3.

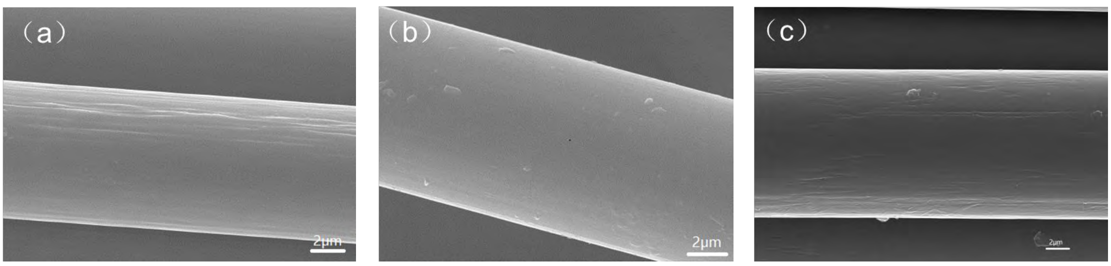

Fig.4. Surface morphologies of the fibers: (a) PI fibers; (b) PPTAⅡ fibers; (c) PPTAⅢ fibers

Table 3. The properties of the fiber reinforced composites

Fiber reinforced composites	0° Tensile		0° Compression		Bending		ILSS (MPa)	Dielectric permittivity (100Hz)	Loss tangent (100Hz)
	Strength (MPa)	Modulus (GPa)	Strength (MPa)	Modulus (GPa)	Strength (MPa)	Modulus (GPa)			
PI/EP	1216.0	79.8	273.3	63.8	742.1	52.9	62,1	3.6	0.01444
Kevlar/EP	1085.4	62.6	199.2	41.6	512.4	38.4	47.9	3.9	0.05979
F12/EP	1779.2	91.5	245.4	71.6	659.2	58.6	64.0	3.8	0.04837

In order to investigate the feasibility of using PI fiber in practical applications, the basic property measurements of the fiber reinforced composites have been carried out, which is demonstrated in table

3. The fiber reinforced epoxy resin composites were fabricated through autoclave molding process. The PI fibers possess very good tensile properties in the longitudinal direction, but it was found that, the tensile strength of the composite deviated from the expected values calculated from the rule of mixture. It was due to the non-homogeneous spread and distribution of fibers. The PI fiber composites possess very high ratio of tensile to compression strength. The compressive strength of the PI fiber is much weaker than its counterparts such as glass, carbon, etc. and thus, its composites, under compressive load, easily failed due to the failure of the fibers, which is attributed to the weak forces between molecular chains of the PI fibers. The PI fibers possess great bending strength in the longitudinal direction which shows the better toughness than the other two fibers. Besides, the mechanical properties of the fiber reinforced composites largely depend on the extent of the fiber matrix interfacial adhesion due to its high surface polarity and roughness, as shown in fig.4.
The dielectric properties of the fiber reinforced composites were measured. The dielectric permittivity and loss tangent of PI reinforced composites are lower than that of PPTA one, which make PI fibers have good potential application in wave-transparent and electronic fields.

Conclusions

Compared with other aromatic fibers, the PI fibers possess significant mechanical properties and thermal properties, and the PI fiber reinforced composites possess a good overall performance, especially in toughness and dielectric properties. Although the ratio of the tensile to compressive strength is high, it is feasible to be used in practical applications. It will be popular for its increasing applications in industrial and advanced technologies.

Acknowledgments

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