Structure and mechanical properties of GR/UHMWPE nanocomposite ropes

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Abstract: Ultra-high molecular weight polyethylene (UHMWPE) and graphene (GR) was melt compounded by reactive extrusion. Nanocomposite monofilaments were prepared by melt spinning through a co-rotating screw extruder and drawing at hot water. GR/UHMWPE nanocomposite ropes were twisted using nanocomposite monofilaments. A structure and mechanical properties of the GR/UHMWPE nanocomposite monofilaments and its ropes had been characterized by scanning electron microscopy (SEM), and mechanical test. Results showed that the monofilaments surface of monofilaments became rougher with introducing of GR nanosheets, which could be related to stacking of GR. The breaking load of GR/UHMWPE nanocomposite ropes was remarkably improved upon nanofiller addition, with the decrease of the elongation at break.

1 Introduction

Polyethylene (PE) monofilaments are the most widely used synthetic materials to replace cotton/hemp for fabricating industrial fishing equipment[1-4], because of their valuable properties, such as low-density and moisture absorption, good mechanical properties, and corrosion resistance. These monofilaments are also used to produce floating cables and nets, lighted fishing equipment, and fishing nets with increased service life. PE monofilament is available as multifilament twisted and monofilament single twines for fishing purposes[5]. PE fishing monofilaments obtained from melt-spun are widely used to ropes, nets cages, gill nets and purse seine. The mechanical properties of fishing rope directly determine the expansion, special offshore work and safety against sea wind and wave. With the development of the modern fishery, higher performance of synthetic monofilaments ropes is needed. The mechanical property of general synthetic monofilament ropes can't meet the large scale, modernization and special offshore operation requirements of fishery production. In particular, UHMWPE fishing ropes have attracted considerable industrial interest because appropriate mechanical performance[6]. However, the large-scale application of UHMWPE ropes in the field of fishing has been limited by their high cost and complicated gel-spinning technique. However, UHMWPE monofilaments can be obtained

by melt spinning. Melt spinning is an efficient, simple, and nonpolluting method. However, the modulus and strength of melt-spun hot drawn monofilaments are still much lower than those of gel-spun monofilament. Thus far, the focus has been on producing high-performance monofilament ropes. Producing high modulus and high strength monofilaments from PE have been one of the challenges in fishing science and technology for a very long time. In the last two decades it has been widely proven that the mechanical properties (such as elastic modulus, strength, fracture toughness, creep stability and fatigue resistance) of various polymeric matrices can be remarkably improved through the addition of very small amounts (less than 5 wt %) of nanostructured fillers [7-14]. And, the improvement of the mechanical properties in reinforced materials depends on the dispersed states of nano-fillers and interactions between polymer and nano-fillers.

In this paper, GR/UHMWPE nanocomposite ropes were prepared, and its morphology and properties were characterized by SEM, DSC and mechanical tensile test.

2 Experimental

2.1 Materials and monofilaments preparation

UHMWPE with a density 950 kg/m^3 was supplied by Sinopec Yangzi Petrochemical Company, China. The

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GR was provided from The Sixth Element Materials Technology Company, China.

GR/UHMWPE hybrids were prepared by reactive extrusion in a twin-screw extruder (Jiangsu, China) at 250 ~ 280 °C from UHMWPE (dried at 80 °C for 12 h) with 0~2 phr GR. The mixing speeding was 60 rpm. The extruded strands were pelletized and dried at 80 °C for 24 h to prepare the GR/UHMWPE hybrid. The GR/UHMWPE hybrid were then melt-spun through a 0.5 mm diameter spinneret using a SJ-45C Monofilament Spin Line equipped with two drawing roll and a collecting roll (Jiangsu, China). The drawn ratio was 24, and the diameter of GR/UHMWPE nanocomposite monofilaments was about 0.35 mm. In the present study, the weight ratios of GR to GR/UHMWPE monofilaments were 0 wt%, 1 wt% and 2 wt%. Correspondingly, the GR/UHMWPE nanocomposite monofilaments were named as UHMWPE, GR/UHMWPE-1 and GR/UHMWPE-2 respectively.

The GR/UHMWPE nanocomposite monofilament ropes with 3-strand were prepared using twisted rope twisting machine. The GR/UHMWPE nanocomposite monofilament was divided first and made into strands. The strands were twisted with GR/UHMWPE monofilament strings and then a number of strands turn around the core to a rope. The lay length was 50 mm, and the diameter was 16 mm. For comparison, the common 3-strand PE ropes were made of the pure PE monofilaments in the same way.

2.2 Characterization

The microstructures of the monofilaments were examined by a JEOL 6360LA scanning electron microscope (SEM) (JEOL Ltd., Japan) operated at an acceleration voltage of 15 kV.

The tensile properties were studied on an Electron Omnipotence Experiment Machine INSTRON-5581 (Instron Instruments, USA) at a cross-head speed of 300 mm/min according to SC/T 5005-2014 and 8834-2016 under ambient conditions. At least three specimens were measured for each sample.

3. Results and Discussion

3.1 Morphology of GR/UHMWPE nanocomposite monofilaments

Figure 1 presents the fracture surface micrographs of GR/UHMWPE nanocomposite monofilaments. The nanocomposite monofilament has a smooth surface. And the SEM images of the fracture surface indicate that the introduction of GR makes the monofilaments surface rougher, which could be related to stacking of GR (see Figure 1).

Figure 1 The SEM micrographs of GR/UHMWPE nanocomposite monofilaments (a) UHMWPE, (b) GR/UHMWPE-1.0 and (c) GR/UHMWPE-2.0

3.2 Tensile mechanical properties of GR/UHMWPE nanocomposite monofilaments

The tensile mechanical properties of GR/UHMWPE nanocomposite monofilaments are shown in Fig. 4. The breaking strength and knot strength of GR/UHMWPE -1 nanocomposite monofilaments increases with introducing GR content, compared with that of UHMWPE monofilaments. By utilizing the load transfer characteristics of GR, the composite can transfer the load to the high strength reinforcement, thereby improving the mechanical properties of the composite. It is noted that the GR/UHMWPE-1 nanocomposite monofilaments has a distinctly superior breaking strength which is 15.4 % higher than that of the pure UHMWPE monofilaments. In addition, GR/UHMWPE-1 nanocomposite monofilament has also (16.9 %) high knot strength. Moreover, it is seen that breaking

strength of blending monofilaments firstly increase and then decrease with increasing GR content. This result is due to the GR agglomeration. The breaking strength of the GR/UHMWPE-2 is 0.8 % lower than the value for the UHMWPE monofilaments.

Table 1 The tensile mechanical properties of GR/UHMWPE nanocomposite monofilaments

Samples	Breaking strength /cN·dtex ⁻¹	knot strength /cN·dtex ⁻¹	Elongation at break /%
UHMWPE monofilament	7.60	3.56	15.3
GR/UHMWPE-1	8.77	4.16	12.5
GR/UHMWPE-2	7.54	3.55	10.8

3.3 Tensile mechanical properties of GR/UHMWPE nanocomposite ropes

GR/UHMWPE nanocomposite rope in diameters of 16 mm was prepared by GR/UHMWPE-1 nanocomposite monofilaments as the basal monofilament. Breaking load is the one of the most important tensile mechanical properties of fishing ropes, and it is also the important indicators when the fishery rope material quality is assessed, and rope is chosen. The comparison of tensile mechanical properties between the GR/UHMWPE nanocomposite rope and UHMWPE monofilaments ropes are shown in Table 2. It can be seen that the GR/UHMWPE nanocomposite monofilament rope has a greater breaking load than UHMWPE monofilament ropes, while it has a lower elongation at break. If the GR/UHMWPE nanocomposite rope is used to replace the 3-strand UHMWPE monofilament rope, the breaking load is improved by 20.8 %. Therefore, the GR/UHMWPE nanocomposite monofilament rope can be used to improve the breaking load and the safety netting gear, which results in great netting gear resistance in seawater, energy saving and consumption reducing.

Table 2 Tensile mechanical properties of GR/UHMWPE nanocomposite rope and pure UHMWPE monofilament ropes

Rope types	Diameter (mm)	Breaking load (kN)	Elongation (%)
GR/UHMWPE nanocomposite rope	16	29.6	22
3-strand UHMWPE monofilament rope	16	24.5	25

4 Conclusion

The breaking strength and knot strength of the nanocomposite monofilament are remarkably improved upon GR addition. And the breaking load

of GR/UHMWPE nanocomposite rope is 20.8 % higher than that of the UHMWPE monofilament.

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