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Erosion characteristics and mechanical behavior of new structural hybrid fabric reinforced polyetherimide composites

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ABSTRACT

In this work, a new structural hybrid fabric reinforced polyetherimide composite was prepared using a solution impregnation method. The effects of fabric orientation, i.e., the angle between the projected line of the impact path of the solid particle on the specimen surface and the axis of the polybenzoxazole (PBO) fibers, and weft density on the erosion behavior of the prepared hybrid composites were investigated. The results show that the erosion rates of the hybrid composites decreased with increasing fabric orientation angle and weft density. No obvious crimp of carbon fibers was observed in the cross-section of a hybrid fabric prepreg sheet, therefore composites with excellent mechanical properties can be obtained. The carbon fibers were covered with PBO fibers and resin, and these protect the carbon fibers from damage well. The prepared hybrid composites showed better erosion resistance than carbon fiber reinforced thermoplastics and better mechanical properties than PBO fiber reinforced thermoplastics. Dynamic mechanical analysis showed that the prepared hybrid composite has high heat resistance.

1. Introduction

Fiber-reinforced thermoplastics (FRTPs) are slowly displacing fiber-reinforced plastics because they are easier to recycle and therefore do not create serious environmental pollution. FRTPs are extensively used as structural materials in various components and engineering parts in the car, airplane, and aerospace industries owing to their excellent specific properties [1]. These vehicles reach high velocities therefore their parts reach high temperatures, so composite materials made from normal thermoplastics cannot be used. An attractive candidate for such applications is polyetherimide (PEI), which is a high-performance amorphous thermoplastic polymer with a glass-transition temperature of $\sim$220 °C, high heat resistance, and excellent mechanical properties [2]. A solution impregnation method, which can decrease the polymer viscosity, has been used to manufacture FRTPs with excellent mechanical properties [3].

Because of the instability of unidirectional fibers, which results in difficulties in the manufacture of FRTPs, woven fabrics with good structural stability in both the warp and weft directions have displaced unidirectional fibers and are increasingly being used in the manufacture of FRTPs. However, the interlacing warp/weft structure includes crimp in the yarns. The weave-like yarn crimp of conventional woven fabrics leads to structural elongation of the fabrics. The elongation reduces the mechanical properties (stiffness and strength) of composites reinforced with woven fabrics [4]. Composites can therefore be manufactured easily and quickly, but at the expense of some of the mechanical properties.

In composite applications, in addition to taking into account their excellent mechanical properties, it should be remembered that composite materials encounter wear and damage caused by erosion by solid particles in the air [5]. Mechanical properties such as the flexural strength can be degraded by the presence of localized impact damage after solid particle erosion. Engineering materials must therefore not only have a high specific strength but also resistance to wear and damage. Polybenzoxazole (PBO) fibers, aramid fibers, or other high-performance ductile fibers have been used to manufacture composites with excellent erosion resistance [6]. However, the tensile moduli and bending properties of these fibers are too poor to meet the requirements for certain applications. A combination of good mechanical and erosion resistance properties is needed for some applications. Carbon fibers have a high mechanical strength and modulus, but their erosion resistance is poor.

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There has been increasing interest in the use of hybrid composite materials because their properties are better than those of the individual material constituents [7]. Hybrid composites are fabricated by combining two or more different reinforcing materials in the same matrix. They are generally used to reduce the costs of manufacturing composites that have a combination of the best mechanical, tribological, and thermal properties. Layered hybrid composites have therefore attracted the attention of researchers. If thin layers of these layered hybrid composites are used, they have to be repaired before some of the wear resistant layers are destroyed, therefore these layers play a significant role in the wear resistance of composites. However, the mechanical properties of thin layered hybrid composites are poor even they have only one or two wear resistant layers. If thick layers of these layered hybrid composites are used, they do not need to be repaired before a few wear resistant layers are destroyed; however, once the wear resistant layers are destroyed, the erosion resistance of the layered hybrid composite decreases sharply. Therefore, it is necessary to develop non-crimp fabric hybrid reinforced composites with excellent erosion resistance and mechanical properties, and high heat resistance. Here, non-crimp means that there is no crimp in the loading direction.

In the present work, to solve the above problems, we developed new structural hybrid fabric reinforced composite materials. Weaving technology and the material properties were used to enable carbon fibers to preferentially act as unidirectional fibers in the fabric, which enables full use of their mechanical properties; the carbon fibers were also covered with polybenzoxazole (PBO) fibers, which can protect them from damage. There have been few reports of this type of structural hybrid fabric and the ways in which they can improve the erosion behavior and mechanical properties of prepared composite materials.

2. Theory

2.1. Proposed new structural hybrid fabric

This section discusses the proposed new structural hybrid fabric, which has excellent mechanical and erosion resistance properties. Because the stiffness of carbon fibers is much higher than that of PBO fibers, and the warp tension is also much higher than the weft tension during weaving, we speculated that in hybrid fabrics carbon fibers are straight, whereas PBO fibers are curved and spread out at the surface of the fabric (as shown in Fig. 1b); this protects the carbon fibers from damage. The mechanical properties of composites reinforced with unidirectional fibers are better in the loading direction than those of composites reinforced with woven fabrics. If our speculation is correct, the new structural hybrid fabric reinforced composites (Fig. 1B) should have better mechanical properties than composites reinforced with traditional woven fabrics (Fig. 1A). Moreover, owing to the presence of PBO fibers in every layer, the erosion resistance properties of the new structural hybrid fabric reinforced composites should be better than those of common layered hybrid composites (Fig. 1C). In Fig. 1, composite A and composite B are obtained from fabric a and fabric b, respectively, and composite C is obtained from fabric a and fabric c.

3. Materials and methods

3.1. Materials

Carbon fibers are widely used as reinforcing materials because of their superior properties such as high mechanical strength and modulus of elasticity, low density, and good flame resistance [8]. Fibers of PBO, which is a rigid-rod isotropic crystalline polymer, have better erosion resistance than carbon fibers or glass fibers and have been used to improve the solid erosion resistance of composites. Two types of unidirectional fibers and two types of fabrics were used in the present study; they are listed in Table 1.

PEI (Product Number 700193, Sigma-Aldrich Co. LLC, Missouri, USA; melting point = 280 °C) was used as a thermoplastic matrix. The solvent for PEI was *N*-methyl-2-pyrrolidone (Kanto Chemical, Tokyo, Japan).

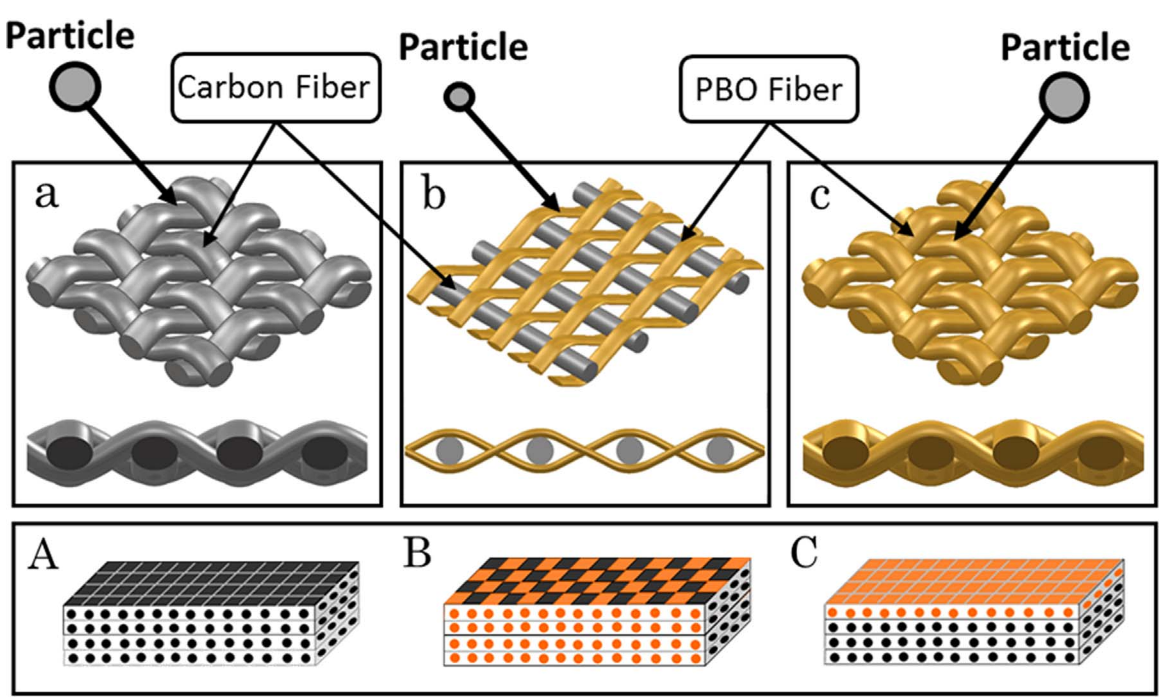

Fig. 1. Schematic diagram of three types of fabrics and composites.