Effect of particle size and volume fraction on tensile properties of fly ash/polyurea composites

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ABSTRACT

Fly ash, which consists of hollow particles with porous shells, was introduced into polyurea elastomer. A one-step method was chosen to fabricate pure polyurea and the polyurea matrix for the composites based on Isonate® 2143L (diisocyanate) and Versalink® P-1000 (diamine). Scanning electron microscopy was used to observe the fracture surfaces of the composites. Particle size and volume fraction were varied to study their effects on the tensile properties of the composites. The tensile properties of the pure polyurea and fly ash/polyurea (FA/PU) composites were tested using an Instron load frame with a 1 kN Interface model 1500ASK-200 load cell. Results showed that fly ash particles were distributed homogeneously in the polyurea matrix, and all of the composites displayed rubber-like tensile behavior similar to that of pure polyurea. The tensile strength of the composites was influenced by both the fly ash size and the volume fraction. Compared to the largest particle size or the highest volume fraction, an increase in tensile strength was achieved by reducing particle size and/or volume fraction. The strain at break of the composites also increased by using fine particles. In addition, the composites filled with 20% fly ash became softer. These samples showed lower plateau strength and larger strain at break than the other composites.

Keywords: polyurea, fly ash, composites, tensile properties

1. INTRODUCTION

Fly ash, a waste by-product generated abundantly in electric power plants, is a hollow micro-balloon ceramic. It is primarily composed of SiO_2 and Al_2O_3. In recent years, the utilization of fly ash as an additive component in metal-matrix composites and polymer-matrix composites has received increased attention. For example, fly ash has been used as filler in aluminum[1], polyester[2], epoxy[3], polyurethane[4], and various rubbers. This development is largely due to the many advantages of fly ash such as low density, strong filling ability, excellent fluidity, and good processibility of the filled materials[5]. Furthermore, as a waste by-product, its usage decreases the overall cost of the composites and the pressure on the environment.

Polyurea is a type of elastomer that is derived from the reaction of diisocyanates with polyamines. It is a stable and 100% solid polymer system that is insensitive to humidity and low temperatures. Furthermore, polyurea elastomer exhibits excellent properties including high thermal stability, abrasion resistance, and superior mechanical properties. Some polyureas are able to reach tensile strengths of 6000 psi and strains of over 500%[6]. In virtue of these advantages, it becomes an outstanding candidate for a coating system that can be applied to a myriad of applications including concrete coating, truck-bed liners, marine coatings, railcar linings, etc[7].

In light of the growing applications, numerous studies have been conducted involving pure polyurea, but no composite material has been developed with polyurea as the matrix. Therefore, in this work, polyurea filled with fly ash is studied to obtain a promising advanced low density composite. Five kinds of composites with various fly ash sizes and volume fractions were prepared and their tensile properties, determined as the tensile stress-strain curve, tensile strength, and strain at break, were compared with those of pure polyurea. The main goal of the present work was to probe the effect of fly ash size and volume fraction on the tensile properties of the filled polyurea composites.

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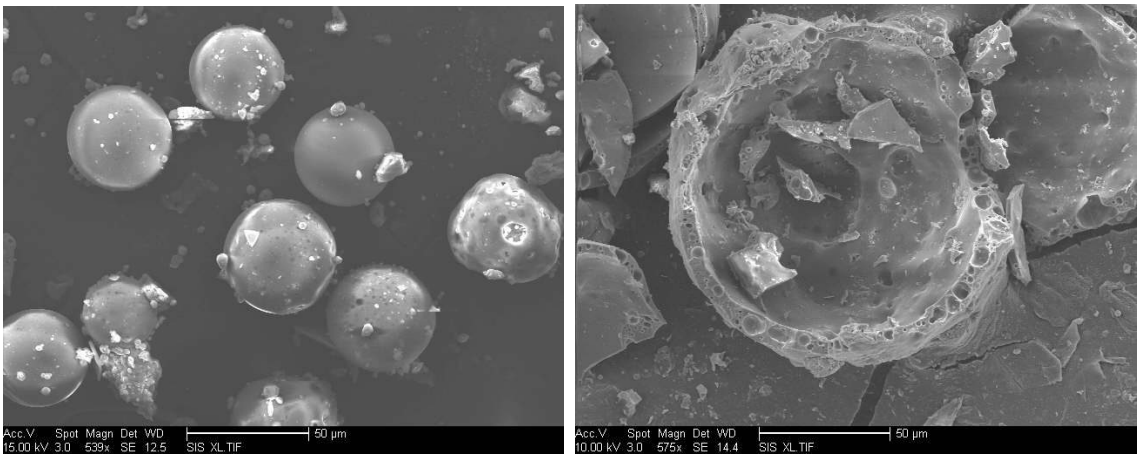
2. EXPERIMENTAL DETAILS

2.1 Material

The fly ash utilized in this study was collected from the Harbin Thermal Power Station in China. It was sieved with a standard mesh sieve column on a mechanical shaker, and the particle sizes in the range of <74 μm, 105μm –149μm, and 177 μm – 420 μm in diameter were used in this study. SEM images clearly illustrate its spherical shape, clean surface, and porous walls, as shown in Figure 1.



a. Intact particles b. Broken particles

Figure 1. SEM images of fly ash prior to casting in polyurea.

Polyurea elastomer (isocyanate component, Isonate 2143L; amine component, Versalink P-1000) was used as the matrix. Theoretically, the isocyanate-to-amine ratio should be 1:1. However, a slight excess of the isocyanate component was used so as to ensure that the reaction went to completion and produced some cross-linking.

2.2 Preparation of composites

Fly ash particles, which were preheated at 110°C for 1 hour and cooled under dry conditions, were introduced into Versalink P-1000 in a predetermined proportion. Using a magnetic stirrer, the mixture was stirred for 2 hours while being degassed in order to achieve a homogenous distribution. Meanwhile, the Isonate 2143L was degassed separately until most of the entrapped air bubbles were removed. These two components were then mixed rapidly for five minutes while degassing. Finally, the mixture was cured in a PDMS (polydimethylsiloxane) mold at room temperature for one week. In order to control humidity levels, the mold was placed in an environmental chamber that maintained a relative humidity level of 10%. Six material configurations were prepared, as shown in Table 1.

Table 1. List of material configurations used in the present study.

Sample type	Fly ash volume fraction	Fly ash size
PU	0%	-
FAPUS5	5%	<74 μm
FAPUM5	5%	105μm –149μm
FAPUL5	5%	177 μm – 420μm
FAPUS10	10%	<74 μm
FAPUS20	20%	<74 μm

2.3 Tests

Scanning Electron Microscopy (SEM) was conducted using a Philips XL30 ESEM scanning electron microscope to observe the distribution of fly ash in the matrix. Composite specimens were immersed in liquid nitrogen until thermal equilibrium was achieved, at which point they were removed and immediately fractured with a hammer. Due to poor conductivity, the fragments were coated with a thin layer of iridium (75 nm thick) in an automatic sputter coater and then the fracture surfaces were observed. The acceleration potential was 15KV.

The tensile properties were measured according to the ASTM standard testing procedure D 412 for elastomers with dumbbell-shaped samples. The tests were performed using an Instron load frame with a 1 kN Interface model 1500ASK-200 load cell. The speed of the crosshead was 7.62 cm/min. A digital camera was used to take a picture of the sample every 10 seconds during testing. By analyzing these pictures, the strain of the samples was obtained. Thereby, the tensile stress-strain curves, tensile strength, and strain at break for all of the samples were determined. Figure 2 shows the test setup. Three samples of each specimen configuration were tested.

Figure 2. Test setup.

3. RESULTS AND DISCUSSION

3.1 Microstructure

Figure 3 shows the fractographs of the composites filled with 5% small size fly ash (<74μm). It is clear from the micrograph that the matrix is very dense and there are no obvious micropores. Moreover, the fly ash particles are distributed homogeneously throughout the matrix.

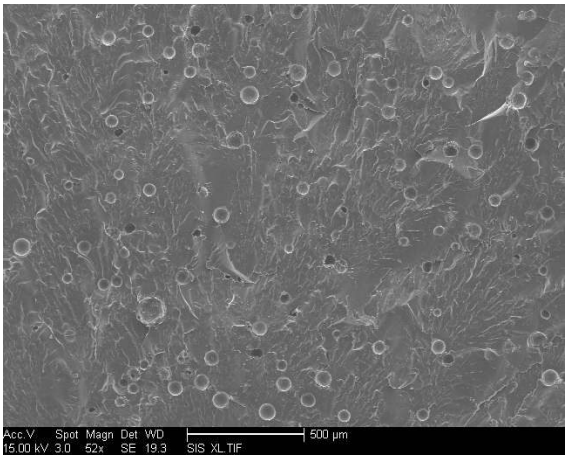


Figure 3. Fractographs of composites filled with 5% small size fly ash (<74μm).

3.2 Tensile properties

The results of the experiments show that the tensile constitutive behaviors of the pure polyurea and the fly ash/polyurea composites are both consistent with the typical rubber-like behavior, which can be divided into three regions: an initial increasing region, a plateau region, and a terminal nonlinear increasing region.

When the fly ash volume fraction is 5%, the terminal increasing regions of the composites filled with different sizes of fly ash begin earlier than that of the pure polyurea. However, this advance is smaller for the composite with large fly ash (177μm-420μm). As the fly ash size decreases, the tensile strength of the composites increases. The strains at break of the composites are smaller than those of pure polyurea, but increase with finer fly ash particles.

The terminal increasing region of the composites filled with 10% fly ash begins earlier than that of the composites filled with 5% fly ash, which begins earlier than that of pure polyurea. When the volume fraction is 20%, the composites become softer, the plateau strength is lower, and the terminal increasing region of the stress-strain curve begins later than that of the pure polyurea. As the fly ash volume fraction increases, the tensile strength decreases and the strain at break decreases initially and then increases.

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