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Erosive behaviors of SiC foam/epoxy co-continuous phase composites

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ABSTRACT

SiC foam/epoxy co-continuous phase composites (SiC_{foam}/EPs) that were composed of the E-51 epoxy (EP) matrix and the SiC ceramic foam (SiC_{foam}) reinforcement were prepared as the erosion resistant materials. The erosive behaviors of SiC_{foam}/EPs were investigated by using a rotating disk rig. The effects of sand content (C), flow velocity (V), test duration and SiC volume fraction on the erosive behaviors of SiC_{foam}/EPs were studied through the mass loss test, SEM and CLSM (Confocal Laser Scanning Microscope) observations. Under different experimental conditions, the erosion rate (E_r, defined as the ratio of erosion (E_c) and time) was relatively larger before the transition point, but E_r clearly decreased after the transition point. E_c of SiC_{foam}/EPs increased with flow velocity ($E_c \propto V^3$) and sand content ($E_c \propto C$). The erosion angle (α, the angle between the eroded and initial surfaces) of SiC_{foam}/EPs increased linearly with flow velocity and sand content. Under the test conditions, flow velocity was the dominant factor for the erosive behaviors of SiC_{foam}/EPs. E_c and α of SiC_{foam}/EPs both decreased with the increase of SiC volume fraction. The erosion of SiC_{foam}/EPs obeyed the linear rule of mixtures (LROM) averaging law since EP and SiC_{foam} were eroded by a parallel process.

1. Introduction

Erosive damage, which is caused by the repeated impact of small, hard and dispersed solid particles in a gas or liquid flow on the surface of materials, has drawn much attention as a severe problem [1,2]. Erosion occurs in various engineering fields, including automobile, aerospace, marine and energetic applications where polymers and polymer composites have been frequently used due to their high specific strength and stiffness [3–5]. And investigations on the erosive behaviors of polymers and polymer composites have been performed extensively.

As for fibers/particles reinforced polymer composites, the erosion process mainly includes removal of the matrix, exposure and breakage of fibers/particles and detachment of the reinforcements from the matrix [6–9]. The erosive behaviors of polymer composites are greatly influenced by the experimental related parameters (impingement angle, impact velocity, erodent type, size, shape, hardness and content) and properties of the matrix and reinforcements. Tewari et al. [10] investigated the influence of impingement angles, exposure time and fiber orientations on the solid particle erosive behaviors of carbon fiber- and glass fiber-epoxy composites. The unidirectional fiber reinforced epoxy composites show semi-ductile erosion behavior and the fiber orientation has a significant influence on erosion. Luo et al. [11] studied the effects of sand content (C), flow velocity (V) and particle diameter (D) on the erosion resistance of fusion-bonded epoxy power coating, and found that the mass loss rate (E) of the coating can be described by an empirical equation, namely $E \propto V^{n1} C^{n2} D^{n3}$. The flow velocity and diameter of emery particle are the dominant factors. Akinci et al. [9] reported that the contact angle of the sand particles and the basalt content are significant factors influencing the erosion rate of low density polyethylene (LDPE) composites. Increase in contact angle of the sand particles and increase in basalt content of the LDPE composites cause to increase in erosion rate, over the 30% basalt content.

As for ceramic foam reinforced polymer-matrix composites, namely co-continuous phase composites, the polymer matrix and the reinforcement of ceramic foam interpenetrate into each other in the composites, giving a co-continuous structure which combines the advantages of the matrix and the ceramic foam. In comparison to the traditional SiC particle reinforced epoxy-matrix composites and the pipeline steel widely used in engineering fields, the mutually supporting effect of the phases in co-continuous phase composites enables composites to perform much better properties, particularly for slurry erosion resistance [12]. Therefore, ceramic foam reinforced polymer-matrix composites can be potentially applied to protect the pumps and pipelines of the desulfurizing systems of thermal power plants which experience not only corrosion but also serious slurry

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erosion brought out by limestone and gypsum particles [13]. However, until now there has been no report on the erosive behaviors of the ceramic foam reinforced polymer-matrix composites. In the present paper, the erosive behaviors of SiC foam/epoxy co-continuous phase composites (SiC_{foam}/EPs) were investigated systematically, including the effects of sand content, flow velocity and volume fraction of SiC ceramic foam on the erosive behaviors of SiC_{foam}/EPs. The erosion model of SiC_{foam}/EPs was discussed.

2. Materials and experimental procedures

2.1. Preparation of SiC_{foam}/EPs

SiC_{foam}/EPs were prepared with the matrix of E-51 epoxy and the reinforcement of SiC ceramic foams. SiC ceramic foams (see Fig. 1a), consisting of α-SiC, β-SiC and Si, were prepared by reaction bonding method [14]. The epoxy matrix was firstly filled into SiC ceramic foams by vacuum infiltration and compression molding; then the specimen was kept at 100 °C and 10 MPa for 4 h in a vulcanization machine, resulting a completely cured epoxy matrix (see Fig. 1b).

2.2. Erosion test

The erosion experiments were carried out using a rotating disk rig (shown in Fig. 2) and the details were described in the previous research [15]. The rotation of the disk on which specimens are fixed was controlled by a motor. The relative movement of specimen and sand–water slurry will result in the impact of sands onto the specimen surface. The equipped circulating system benefited to control the experimental conditions of temperature, suspension of the solid particles, etc. In the present paper, the rotation speed of specimen was defined as the flow velocity. The slurry consisted of water and commercial quartz sands with the grain size of 70–150 mesh (shown in Fig. 3). The specimen surfaces were finally ground with 1000 grid abrasive papers followed by cleaning with deionized water and dried before tests. The original surface of SiC foam is exposed completely. After the erosion tests, the specimens were cleaned, dried and weighed using an electrical balance with the accuracy of 0.1 mg.

In order to investigate the effects of flow velocity and sand content on the erosive behaviors of SiC_{foam}/EPs, different flow velocities were obtained by varying the rotating speed and keeping the sand content at 10 kg m^{-3}, and different sand contents were obtained by varying the quartz sand mass percent in the slurry and keeping the flow velocity at 10.5 m s^{-1}. The effect of SiC foam volume fraction on the erosive behaviors of SiC_{foam}/EPs was studied with the flow velocity of 10.5 m s^{-1} and the sand content of 10 kg m^{-3}.

2.3. Characterization of the erosion

In order to investigate the erosion mechanism of SiC_{foam}/EP, the morphologies of the eroded surfaces were observed with a scanning electron microscopy (SEM) (Inspect F50). The erosion angles (α) were measured from the figures observed by a stereoscopic microscope (OLYMPUS SZX16). Meanwhile, the profiles of the eroded

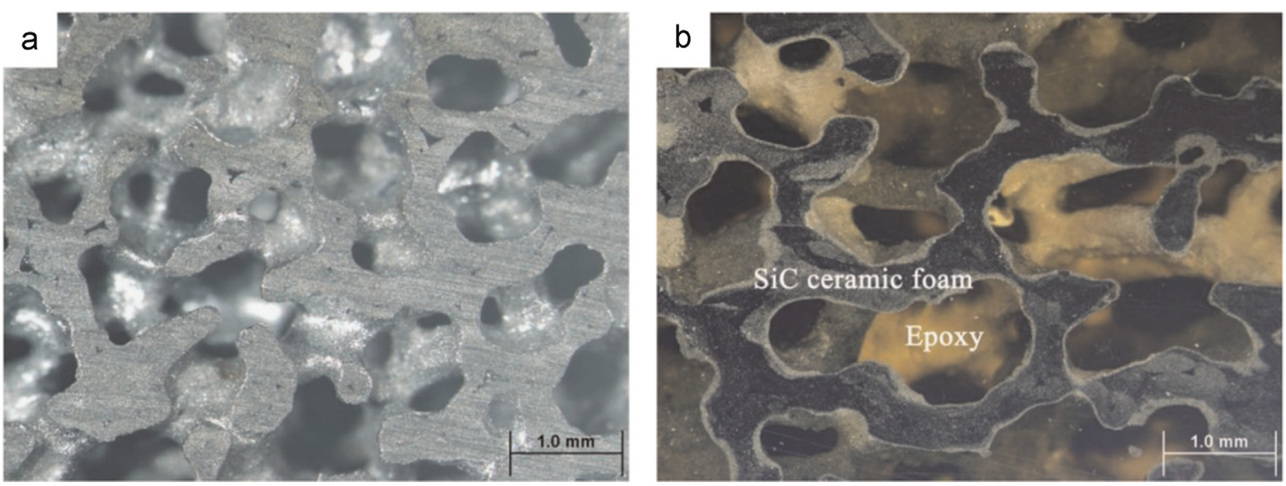

Fig. 1. Cross-sections of (a) SiC ceramic foam and (b) SiC_{foam}/EP.

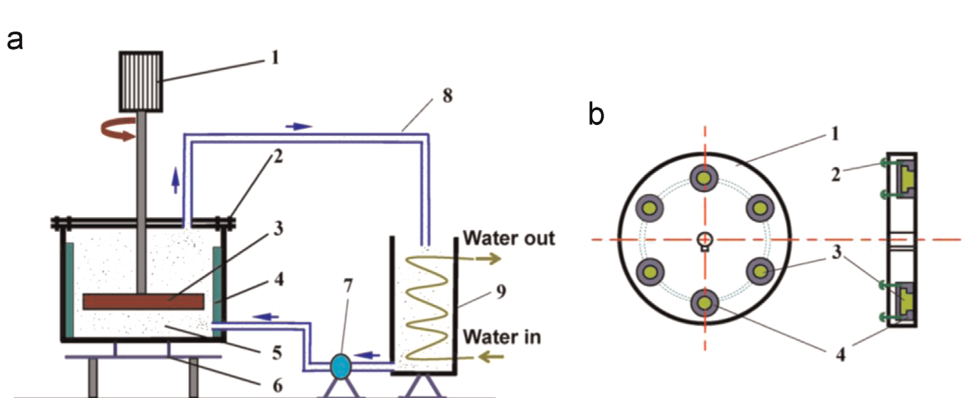

Fig. 2. Sketch of the slurry erosion equipment and specimen. (a) Rotating disk equipment 1 – motor, 2 – bolt, 3 – disk, 4 – baffle, 5 – container, 6 – supporter, 7 – circulating pump, 8 – circulating lines, 9 – cooler. (b) Disk and specimen 1 – disk, 2 – bolt, 3 – specimen, 4 – plastic specimen holder.