Wear 332-333 (2015) 979–987

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Preparation and its cavitation performance of nickel foam/epoxy/SiC co-continuous composites

Y. Liu, D.L. Duan *, S.L. Jiang, S. Li

Institute of Metal Research, Chinese Academy of Sciences, Shenyang Liaoning 110016, China

ARTICLE INFO

Article history:
Received 20 September 2014
Received in revised form
15 November 2014
Accepted 15 December 2014
Available online 25 December 2014

Keywords:
Co-continuous composites
Preparation
Interface
Cavitation performance
Nickel foam

ABSTRACT

Co-continuous composites are a new class of composites with a unique topological structure. In this study, nickel foam/epoxy/SiC co-continuous composites were designed and prepared through a vacuum infusion process to improve the service life of materials used for corrosive erosion conditions. Optical microscope and scanning electron microscopy coupled with energy-dispersive spectrometry were used to characterize the morphology and element distribution of the composites. The impact strength of these composites was evaluated according to GB1943-2007. Their cavitation performance was studied with an ultrasonic cavitation tester in 0.1 M HCl aqueous solution, 0.1 M NaOH aqueous solution and deionized water. Results indicated that the epoxy mixture completely filled the void space of the nickel foam, the resin and metal compactly combined with each other and SiC reinforcement increased the impact strength of the composites. The cavitation experiment demonstrated that maximum weight loss occurred in the acid medium. Three sources of damage were found: the preferential failure of the metal phase because of mechanical action, chemical action and their synergetic effect; the brittle failure of the resin phase resulting from the cavitation loading; and a large quantity of peeled-off resins induced by the interface effect. Porous metal can effectively prevent crack expansion in the resin phase.

1. Introduction

Co-continuous composites, also called interpenetrating phase composites, are a new class of composites with interpenetrating microstructures, in which both metal and resin phases are topologically continuous and interconnected three-dimensionally throughout the structure. The co-continuous composites were initially proposed by Clarke [1] and became a research hot spot in the materials field during the last two decades [2–8]. Compared with the traditional particle and fiber reinforced composites, this kind of composites enables both matrix and reinforcement phases to keep more advantages in the composites based on the special continuous structure and topological uniformity. Therefore, co-continuous composites possess unique mechanical properties, friction and wear properties, damping performance and thermal properties [9–14]. They also prevent anisotropism in traditional composites and have great development prospects.

The materials used in the hydrometallurgy industry, energy industry and other chemical industrial processes usually undergo a special working condition of corrosive erosion, in which premature material failure occurs. For examples, some key parts in process industry (e.g., agitators, pumps and valves) experience serious corrosion and cavitation erosion. Tubular heat exchangers, last stage blades of steam turbine and carrier-based aircrafts undergo service conditions like corrosive droplet erosion. This phenomenon results in potential safety hazards and significant profit loss. The requirements for both erosion and corrosion are difficult to meet for single-phase materials. Composites have therefore become a new trend in the development of materials. Stress in the composites may rapidly disperse through a 3D metal network because both phases of co-continuous composites are continuous and interpenetrating. This process improves the loading capacity of the composites and makes them suitable for corrosive erosion conditions.

However, research on co-continuous composites is still at an early stage. In terms of preparation, co-continuous composites are produced by the combination of metal and ceramic [15–17] or metal and polymer [18–21]; no third component is introduced. As for the application, cushion materials have been created because of the damping property of co-continuous composites, whereas friction and self-lubricating materials have been developed because of the topological structure of co-continuous composites [22,23]. To date, no research on the corrosive erosion performance of co-continuous composites has been reported.

* Corresponding author. Tel.: +86 24 23971773; fax: +86 24 23971778.
E-mail address: duandl@imr.ac.cn (D.L. Duan).

http://dx.doi.org/10.1016/j.wear.2014.12.025
0043-1648/

In this study, we propose to combine all three categories of traditional materials: metal, polymer and ceramic. We aim to produce co-continuous composites with high corrosive erosion resistance. Porous metal nickel was used as the first topologically continuous phase. Epoxy resin reinforced by SiC powder was introduced into the open cells of the nickel foam as the second continuous phase, which is interpenetrating with the first metal one. The nickel foam/epoxy/SiC co-continuous composites were prepared through a vacuum infusion technique with the use of a self-made apparatus. Since it is widely believed that the microjet is the damage mechanism of cavitation, cavitation could be used to simulate the droplet erosion. Thus the cavitation performance of co-continuous composites in a corrosive medium was preliminarily studied.

2. Experimental methods

2.1. Preparation of the nickel foam/epoxy/SiC co-continuous composites

2.1.1. Materials

SiC powders with three different groups of 40 nm, 600 nm to 800 nm and 5 μm in mean particle size were provided by Shanghai Chaowei Nanotechnology Co. Ltd. The purity of the powders is more than 99.5%.

Nickel foam with a density of 1.4 g/cm^3 and 100 pores per inch was fabricated by Jilin Zhuoer New Material Co. Ltd. The average pore size is approximately 0.2 mm, the thickness of prisms is about 35μm, and the porosity is 84.3%.

The epoxy used in this work is bisphenol A epoxy resin (WSR6101) with an epoxy value of 0.41 to 0.47 eq/100 g. The corresponding curing agent is low molecular weight polyamide 651(PA651) with an amine value of 400 ± 20 mg KOH/g.

Alkyl (C12–C14) glycidyl ether (AGE) with an epoxy value of 0.34 to 0.37 eq/100 g bought from Hengyuan Chemical Co. Ltd. was used as the reactive diluent.

The silane coupling agent KH550 with CAS registry number 919-30-2, namely, γ-aminopropyltriethoxysilane, was used to improve the adhesion property between the matrix and the reinforcement.

2.1.2. Preparation method

The nickel foam/epoxy/SiC co-continuous composites were prepared with vacuum infusion method. The specific experimental steps are as follows:

1) Pre-treatment of nickel foam and SiC powder
   The silane coupling agent was hydrolyzed for 1 h in an ethanol–water solution with a KH550-distilled water–ethanol mass ratio of 1:2:10. The cleaned nickel foam was added to the hydrolyzed silane coupling agent solution, and the mixture was then placed in an ultrasonic cleaner and vibrated for 10 min. The nickel foam dried at a temperature of 150 °C for 1 h. SiC powder was added to the hydrolytic silane coupling agent solution and dispersed with a high-speed shear mixer for 10 min. The mixture was rinsed with alcohol and dried at a temperature of 100 °C for 2 h after filtration.
2) Mixture of the SiC powder and epoxy resin
   The epoxy resin was mixed with the reactive diluent AGE in 50 °C water bath, and the pre-treated SiC powder was added to the epoxy resin and dispersed with a high-speed shear for 10 min. Then, the curing agent PA651 was added to the epoxy resin and stirred to form the uniform mixture. Table 1 shows the various substances and their proportions.

Table 1
Materials in the epoxy mixture and their proportion.

Materials	Epoxy E-44	Reactive diluents age	Polyamide 651	SiC
Mass fraction	100	20	50	20

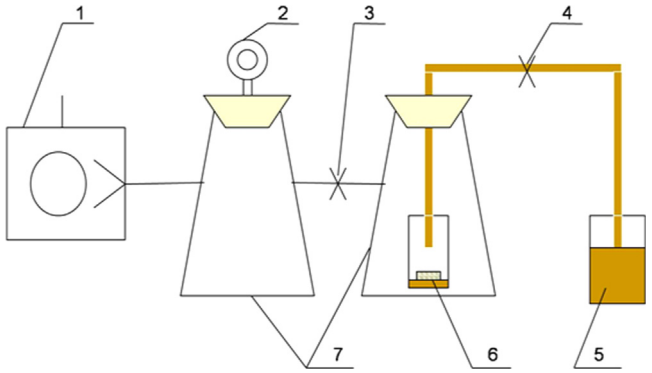

Fig. 1. Schematic of the self-made experimental apparatus for vacuum infusion: 1. vacuum pump; 2. vacuum gauge; 3. tee coupling; 4. hose and clamp; 5. mixture; 6. samples; 7. conical flask.

3) Vacuum infusion process
   Fig. 1 illustrates the schematic of the self-made experimental apparatus for vacuum infusion. The beaker containing the nickel foam samples was placed into a conical flask at the beginning of this step. The clamp was loosened when the vacuum level of the chamber was more than 2,000 Pa because of pumping for a certain period, and then the mixture flowed into the foam under negative pressure. The hose was clamped, and the tee coupling was switched to air when the samples were immerged by the mixture.
4) Curing of the resin mixture
   The samples were removed from the beaker after the fluidity of the resin mixture decreased. The samples were then cured at room temperature.

Scanning electron microscopy (SEM) coupled with x-ray energy-dispersive spectrometry (EDS) was used to characterize the surface microstructure and chemical composition of the co-continuous composites.

2.2. Cavitation test

A vibratory cavitation apparatus was used to examine the cavitation performance of the present co-continuous composites. Fig. 2 shows the schematic of the cavitation test setup.

All the samples were ground with 800# silicon carbide paper and washed with ethanol in an ultrasonic cleaner. Then, the samples were dried at a temperature of 120 °C for half an hour and weighed with an electric balance with a precision of 0.1 mg. The test sample was mounted in a sample holder and placed 0.5 mm apart from the tip of the vibratory horn of an ultrasonic generator FS-600 N provided by Shanghai Sonxi Ultrasonic Instrument Co., Ltd. A frequency of 20 kHz, a peak-to-peak amplitude of 60 μm and a power of 300 W were set in this study. The test duration is 10, 20, 30, 60, 90 and 120 min. The test media included 0.1 M HCl aqueous solution, distilled water and 0.1 M NaOH aqueous solution.