

Friction and wear behavior of SiC particles deposited onto paper-based friction material via electrophoretic deposition



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ABSTRACT

In order to improve the friction and wear properties of the paper-based friction materials, SiC particles (SiCp) were uniformly deposited onto the paper-based friction material via electrophoretic deposition with 300 V, 400 V and 500 V deposition voltages, obtaining the SiCp-content of 10.8, 15.9 and 22.9 wt%. The microstructure and thermal stability of the paper-based friction materials were characterized by scanning electron microscope (SEM) and thermogravimetry (TG). And the porosity, mechanical and tribological properties of samples were tested by mercury injection apparatus, electromechanical universal testing machine and friction tester. The results show that the uniform distribution of SiCp in the paper-based friction materials decreases the porosity and obviously improves the thermal stability and mechanical properties. Meanwhile, the incorporation of SiCp increases the stability of friction coefficient and the wear resistance of paper-based friction materials. Especially, the wear rate of paper-based friction material with 400 V deposition voltage treatment (CP400) for optimal SiCp-content of 15.9% decreases by 51.2% from 5.8×10^{-14} to 2.8×10^{-14} m³/(N·m) compared with that of the bare paper-based friction material (CP0). The electrophoretic deposition techniques provide the possibility of uniform addition of micro-nano particles to the paper-based friction material, which is beneficial to improve the friction and wear properties.

1. Introduction

Paper-based friction materials are commonly used in oil-immersed clutches and lock-up mechanisms [1,2], which usually consist of various ingredients such as fibrous reinforcement, binders, fillers and friction modifiers [2]. However, the main troubles of paper-based friction materials are low thermal stability and poor interfacial bonding between fiber and resin matrix, which could potentially lead to the failure of paper-based friction materials [3,4]. Different types of carbon fibers with outstanding properties are gradually used as reinforcements in composites [5–8], which could improve the heat resistance to some extent. Furthermore, the addition of inorganic particles could also improve the heat resistance and interfacial adhesion. The silicon carbide particles (SiCp) [9] belong to this category, and show many physicochemical properties in terms of hardness, refractoriness, thermal conductivity, and thermal stability, to name explicitly a few of tribological interest.

Researchers developed a variety of methods to disperse the SiCp into the matrix and studied the effects of SiCp on the properties of the composites. Sharma S [10] studied the influence of amount and size of SiCp

on wear performance of SiC-UHMWPE nano-composites. The introduction of SiCp by ultrasonic dispersing method were proved beneficial for enhancing wear resistance (approximately 15%) and the optimum amount for micro-filler was around 8%. Sareh MS [11] investigated the effects of nanosized SiCp content on the friction performance of Al/SiC nanocomposites. The friction coefficient and frictional heat of the composites containing the mechanically mixed addition of SiC drastically reduced compared with that of the base alloy. Wu Y [12] studied the friction and wear performance of Ni–P composites by reinforcement with PTFE and/or SiC particles. The SiCp were introduced by electroless plating method, which was responsible for the good tribological properties of the hybrid Ni–P–PTFE–SiC composites at high load. Mohammad MG [13] studied the wear behavior of Al 5252 alloy reinforced with micrometric and nanometric SiC particles. Al 5252 alloy powder and nano-composite powders of SiC particles were produced using the in situ powder metallurgy method. The composite reinforced with micrometric SiC particles indicated the lowest wear rate at the applied stresses of 0.3 and 0.6 MPa, while the nano-composites exhibited the best wear resistance at the normal stress of 0.9 MPa. The SiCp are introduced into the

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Table 1
The compositions and content of the samples.

Classification	Ingredient	Wt%
Reinforced fibers	Carbon fiber	40
	Kevlar fiber	10
	Cellulose fiber	10
Binder	nitrile butadiene rubber modified phenolic resin	20
Fillers	Barium sulfate (BaSO ₄)	6
	Kaolin	6
	Calcium carbonate(CaCO ₃)	8

composite materials and exert its strengthening and abrasion resistance. However, it is difficult for SiCp to be evenly added to the inside of composites by above-mentioned methods.

The electrophoretic deposition (EPD) technique is adopted to resolving issues associated with the poor SiCp dispersion in composites with the advantages of short formation time, no requirement for binder and controllable process [14,15]. The SiCp distribute evenly on the surface of the reinforcing fiber and fill into the pores by EPD, which will take full advantage of the synergistic effect of SiCp and reinforcing fiber and effectively improve the friction and wear properties of paper-based friction materials.

In this paper, the SiCp are uniformly deposited onto the surface and even interior of preform of paper-based friction materials by EPD with different deposition voltage, altering the micro structure of the paper-based friction materials. The objective of current work is to explore the effects of SiCp on thermal stability, mechanical and tribological properties of paper-based friction materials with different deposition voltage. Furthermore, EPD techniques provide a means to uniformly introduce micro-nano particles into composites, which is beneficial to obtain excellent performance of paper-based friction materials.

2. Experimental details

2.1. Raw materials

PAN-based carbon fibers with 7 μm in diameter (Jilin Jiyan high technology fiber Co., Ltd. China) were used as the main reinforcement. Aramid fibers (DuPont, USA) and cellulose fibers were also added to improve the flexibility and toughness of the friction materials. The nitrile butadiene rubber modified phenolic resin power (Jinan Shengquan Hepworth Chemical Co., Ltd. China) containing hexamethylenetetramine as curing agent was used as binder. The mixture of barium sulfate, kaolin and magnesite were used as space fillers. Silicon carbide particles (SiCp) with 0.5 μm in average size, Isopropyl alcohol ((CH₃)₂CHOH) and iodine (I₂) were obtained from Laiyang Kant chemical industry Co., Ltd. in China. The SEM image of main raw materials including carbon fibers,

aramid fibers, cellulose fibers and SiCp was shown in Fig. S1. The compositions and content of bare paper-based friction material involved in this study were summarized in Table 1.

2.2. Electrophoretic deposition of SiCp

The reinforced fibers containing carbon fibers, aramid fibers and cellulose fibers were mixed in water by a mixer for 3 min, and then all the fillers were added into water and stirred for 1 min. The preform sheets were obtained by paper-making machine from the mixture mentioned above via filtration and rolling. Then the preform sheets were dried at room temperature. Hybrid components including 2 g SiCp + 150 ml (CH₃)₂CHOH + 0.15 g I₂ were stirred for 24 h to obtain precursor solution of SiCp. The preform sheets were cut into a square (50 mm $\times$ 50 mm) as a cathode to deposit SiCp. The graphite plate (50 mm $\times$ 50 mm $\times$ 5 mm) was used as an anode, the anodic and cathodic electrodes were mounted parallel to each with the distance of 30 mm. The process of deposition SiCp were carried out with different voltage of 300 V, 400 V and 500 V for 2 min with two sides. Finally, the preform sheets containing SiCp were dried at room temperature. The untreated and treated sheets at different electrophoretic deposition voltages of 300 V, 400 V and 500 V were designated as E0, E300, E400 and E500, respectively.

2.3. Preparation of paper-based friction materials

Resin was infiltrated into the preform sheets with ethanol as solvent. After infiltrated, the preform sheets were dried again at room temperature, followed by hot pressing at 170 $^{\circ}\text{C}$ for 10 min with the pressure of 10 MPa by vulcanizing machine. Thus, SiCp reinforced paper-based friction materials were obtained. The paper-based friction materials containing untreated and treated preform sheets at different deposition voltages were designated as CP0, CP300, CP400 and CP500, respectively. The schematic of overall fabrication process was illustrated in Fig. 1.

2.4. Testing method and equipment

The surfaces of the samples were observed by scanning electron microscope (SEM, JEOL 6460 and Hitachi S4800). The porosity of the samples was measured by mercury analyzer (AutoPore IV 9500). The surface contour and the roughness of the samples were carried out by confocal optical microscope (C130). The thermogravimetry (TG) traces of the samples were measured by a thermogravimeter (NETZSCH STA 409 PC/PG Seiko Instruments, TG/DTA-220U) at the elevating rate of 10 $^{\circ}\text{C}/\text{min}$ under air atmosphere. The chemical composition was determined by energy dispersive spectroscopy (EDS, JED-2200 Series). The element distribution was measured by X-ray Analytical Microscope

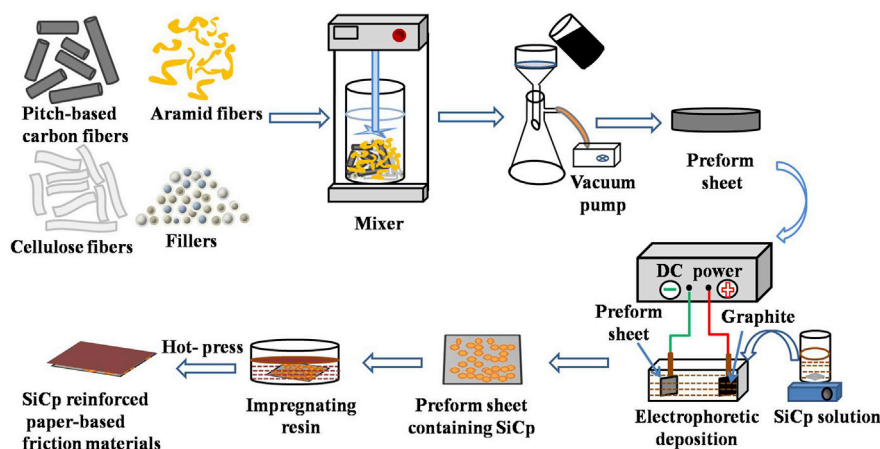


Fig. 1. The schematic of overall fabrication process for paper-based friction materials with electrophoretic deposition SiCp.

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