EFFECT OF POROSITY ON PARTICLE EROSION WEAR BEHAVIOR OF LAB. SCALE SIC_F/SIC COMPOSITES

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The use of silicon-based ceramics and composites as combustor liners and turbine vanes provides the potential of improving next-generation turbine engine performance, through lower emissions and higher cycle efficiency, relative to today's use of super alloy hot-section components. As a series of research for FOD resistant, a particle erosion wear test was carried out for continuous Pre-SiC fiber-reinforced SiC matrix composites with a new concept of lab. scale fabrication by LPS process. The result shows that aperture (some form of porosity) between fiber and interface has a deleterious effect on erosion resistance. Aperture along the fiber interfaces consequently causes a severe wear in the form of fiber detachment. Wear rate increase proportional as contents of open porosity increases. For nearly full dense composite materials of about 0.5 % porosity, are about 200 % more wear-resistant than about 5 % porous composites. Grain growth and consolidate condition of matrix which directly affects to FOD resistant are also discussed.

Keywords: Erosion; wear; porosity; silicon carbide; composite; ceramic.

1. Introduction

Silicon-based advanced high-temperature ceramics and composites are prime candidates for heat engine and heat exchanger structural components.[1-7] Conventional materials require a large amount of cooling, which reduces the turbine inlet temperatures, thereby reducing the thermal efficiency. Silicon carbide (SiC) has one of the highest wear resistant of all single-phase ceramics due to the high hardness[6-8] and continuous SiC fiber-reinforced SiC matrix composite (SiC_f/SiC) has one of the most advanced composite material system due to commercial availability[9] and high temperature stability. Erosion, a term of progressive loss of original material by foreign object damage (FOD), is one of the key issues in application and it result in significant costs if not adequately controlled. A review of literatures found few works regarding SiC_f/SiC

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composites under erosion. This study examines the microstructure of hot-pressed SiC_f/SiC composites not only to examine the wear behavior occurred by impingement of solid particle, but also to clarify the dominant mass loss mechanisms.

2. Experimental procedure

Pre-SiC fiber tows were employed as reinforcement, and were selected because of cost effectiveness. The pyrolytic carbon (PyC) was employed for matrix-fiber interface. Nano-powder Infiltration and Transient Eutectoid (NITE) process,[10] a highly optimized liquid phase sintering (LPS) process which are available in commercial, has been selected to fabricate test materials for erosion resistant evaluation.

2.1. *Material*

Unidirectional fiber tows were impregnated in SiC nano-slurry, which is mixture of SiC nano-powder and sintering additives (Al_2O_3+Y_2O_3=10 wt % as 6:4 ratio). Each specimen has same composition and sintering conditions, such as a temperature, holding time, and applied pressure, as 1850 °C for 1.5 hr in Ar atmosphere under 20 MPa of applied pressure. Constituent variables for fabrication are amount of used PyC for interface and treatment for porosity control; a special treatment was employed to one of the fabrication process to obtain a high densification material. Three kinds of hot-pressed SiC_f/SiC composite materials were fabricated by NITE process for erosion wear test; a) with thick interface: $specimen_{thick@I}$, b) with thin interface: $specimen_{thin@I}$, and c) with thin interface and treatment: $specimen_{thick@I,T}$.

2.2. *Densitometry test*

Densitometry test was carried out by the Archimedean method to examine the density and content of porosity after fabrication of each specimen. Open porosity can be measured by this method and also, bulk density, and apparent density.

$$d_{bulk} = \frac{W_{da}}{W_{wa} - W_{ww}} \rho_{water}(T) \cdot \tag{1}$$

$$d_{apparent} = \frac{W_{da}}{W_{da} - W_{ww}} \rho_{water}(T) \cdot \tag{2}$$

$$v_{op} = \frac{d_{apparent} - d_{bulk}}{d_{apparent}} \times 100 \cdot \tag{3}$$

where W_{da}, W_{wa}, and W_{ww} is the weight of sample with the conditions of dry in air, wet in air, and wet in water, respectively.
Density and porosity of hot-pressed specimens are summarized in Table 1.

Table 1. Density and porosity of hot-pressed specimens by quantitative measurement.

Material	SiC_f/SiC composites materials		
Interface thickness	Thin with treatment	Thin	Thick

Apparent density, $d_{apparent}$ [g/cm^3]	3.08	2.89	2.77
Bulk density, d_{bulk} [g/cm^3]	3.06	2.74	2.66
Open porosity, v_{op} [%]	0.50 ± 0.037	5.08 ± 0.04	4.2 ± 0.04

2.3. *Erosion wear test*

Erosion wear test was carried out by SiC powder impingement using gas jets to utilize repeated impact erosion with a small nozzle delivering a compressed gas containing those abrasive particles which impacts the surface of a test specimen which coincident with ASTM G76 as shown in figure 1. Table 2 shows the experimental conditions for the test.

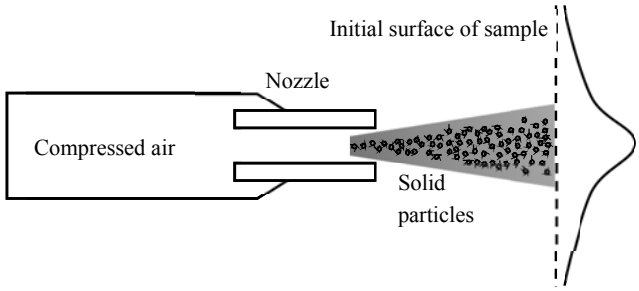

Fig. 1. Schematic of the solid particle impingement using gas jet.

Table 2. Experimental conditions for the erosion test.

Parameter of test	Erosion method	Erodent	Step of erosion	Impingement conditions		
				Angle	Distance	Jet pressure
Value	Gas jet with solid particle	SiC powder GC[a] #36	3 steps	90 °	40 mm	5 atm

[a]Green carborundum (GC) is a bulk grinding compound for polishing purpose

3. Results and discussion

3.1. *Microstructure of the materials*

The employed amount of PyC for specimen$_{thick@I}$ is more than specimen$_{thin@I}$, as shown in figure 2. The SE micrograph in back scattered electron imaging (BEI) mode indicates fibers and PyC in color of gray and black, respectively. specimen$_{thick@I}$ has the volume fraction of PyC about 3 times larger than specimen$_{thin@I}$ has for fiber coating.

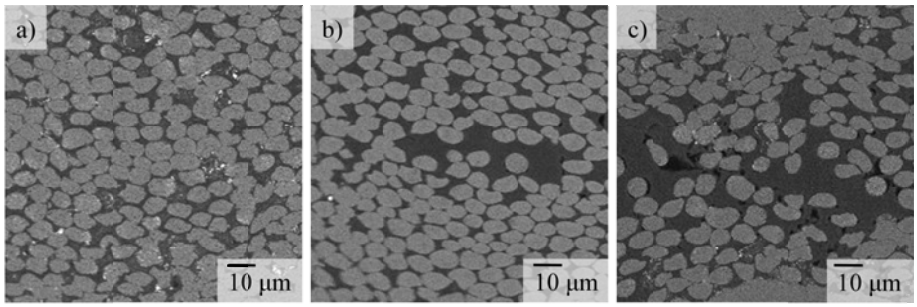

Fig. 2. Employed amount of PyC in a typical region of composite, normal to the fiber direction of a) specimen$_{thin@I,T}$, b) specimen$_{thin@I}$, and c) specimen$_{thick@I}$ for interface.

Porosity of specimen$_{thick@I}$ was mainly observed in two kinds of form as shown in figure 3; one is as (a) pores between remnants agglomerates (right) compared with dense matrix (left). Other is (b) an aperture between fiber and interface, and it causes fiber pulled-out and fiber detachment. These inadequately pressurized area and insufficient grain growth are some of the dominant reason of severe mass loss.

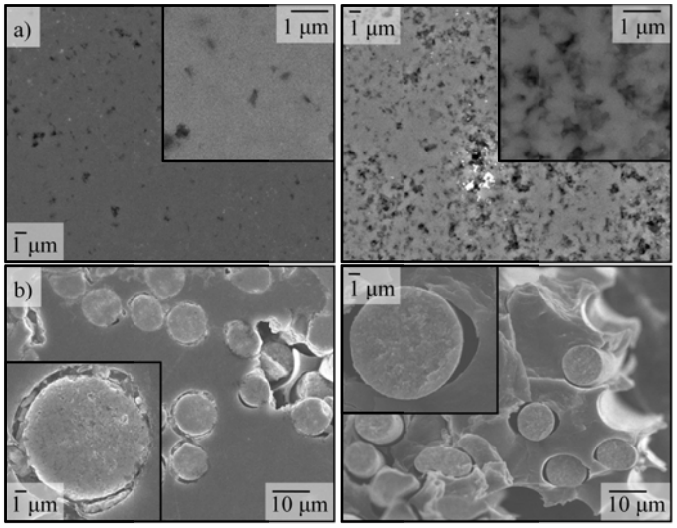

Fig. 3. SE micrographs of a typical porous (a) in dense matrix and in coarse matrix, (b) along fiber interface, and fiber pulled-out and fiber detachment for specimen$_{thick@I}$.

3.2. *Erosion Wear volume*

SiC particles were impinged onto the specimen as erodent for three steps and at each step the wear amount was measured by surface profilometer. The results are shown in figure 4 (a). The specimen with thick interface (specimen$_{thick@I}$) shows better erosion resistibility rather than the specimen with thin interface (specimen$_{thin@I}$). The correlations of wear rate and contents of open porosity are shown in figure 4 (b). Thin interface with special treatment shows the best erosion resistant. This result indicates that the contents of open

porosity have more affects on erosion wear than the amount of employed PyC for interface in composites.

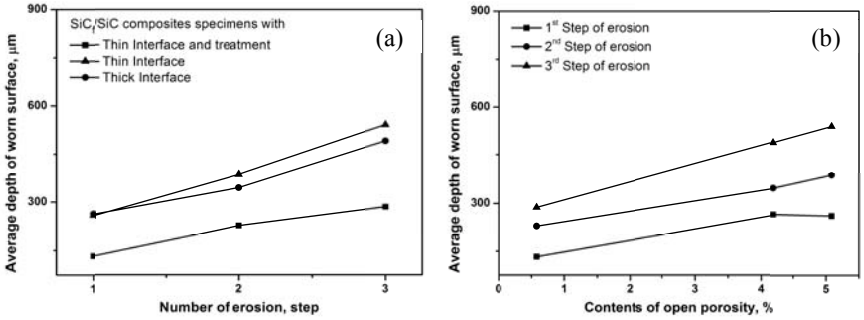

Fig. 4. Wear amount as a function of (a) number of erosion step, and (b) open porosity.

3.3. *Microscopic observation of Eroded surface*

The eroded surface of each SiC_f/SiC composites was examined by SEM in order to examine the dominant parameter for wear behavior.

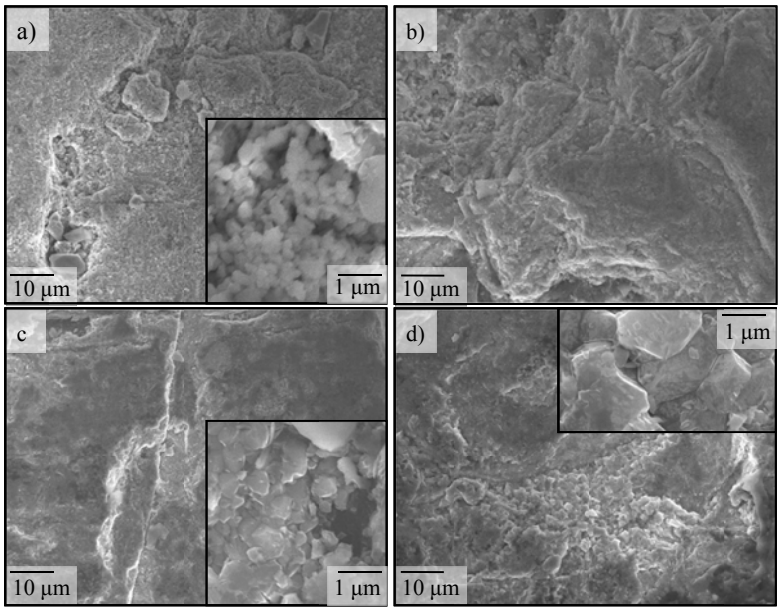

Fig. 5. Eroded surface at a) inadequately pressurized area of $specimen_{thick@I}$, b) a typical region of $specimen_{thick@I}$, c) $specimen_{thin@I}$, and d) $specimen_{thin@I,T}$.

Different erosion wear behavior was observed as shown in figure 5. Because, the inadequately applied pressure area occasionally exists, phenomenon of insufficient densification and scarcity grain growth were observed as figure a) comparing with b). Consequently, the grain growth and consolidate condition has been altered for each

sample material, due to the existence of porosity after pre-pyrolysis process of fiber and PyC interface for $specimen_{thick@I}$ and $specimen_{thin@I}$. By considering the effect of the treatment, there is a great chance that this porosity has been produced by both contractibility of PyC precursor at pre-pyrolysis process and Pre-SiC fiber at hot-press process.

4. Conclusion

Tribological studies of Pre-SiC fiber-reinforced SiC composites on particle erosion wear showed that:

-Contraction of Pre-SiC fiber during crystallization process, generates aperture between fiber and interface,

-The aperture has a deleterious effect on the resistances of materials to erosion wear,

-The aperture along the fiber interfaces, provoke a fiber detachment,

-Porosity in inadequately pressurized area act as a defect in matrix, consequently, cause easy crack propagation and grain pull out,

-It is assumed that the porosity is generated by a contractibility of PyC precursor at pre-pyrolysis process where the vaporized component of precursor generates gaseous phase in a certain temperature.

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