§54. Crack Initiation and Growth Characteristics in SiC/SiC Composite under Indentation Test

Zhang,W., Katoh,Y., Hinoki,T., Kohyama,A. (Kyoto Univ.)
Noda, T. (National Research Inst. of Metals)
Muroga, T.

SiC/SiC composites are potential structural materials for fusion because of their high temperature strength, low induced radioactivity, non-catastrophic failure mode, high plant heat efficiency and good irradiation resistance. Nevertheless, composites' brittleness is still a problem. For improving the toughness of the materials, a key element is the fiber/matrix interfacial layers, which is deposited on the fibers prior to Chemical Vapor Infiltration (CVI) matrix forming processing. In our previous work, as the interphase thickness increased, a reduction in the ultimate bend strength occurs accompanied by a more gradual load drop-off as load is no longer effectively transferred from matrix to fibers. The crack behaviors among fibers, interphase and matrix influence the fracture performance of SiC/SiC composites significantly. However, up to now, there are almost no reports about crack behavior under indentation test. In this work, push-in test and micro hardness test were carried out on specimens with various thickness carbon layer and multiple layers to investigate the effect of carbon layer and multiple layers on crack initiation and propagation.

For investigating the effects of fiber coatings on crack behavior of SiC/SiC composites, different thickness carbon coating and multiple coatings were employed prior to SiC CVI processing. The thickness of coating ranged from 50 to 5500nm. Multiple coatings refers to consecutive depositions of C, then SiC, then C.

From the push-in test of thin specimens with thickness below 100 μm and with maximum load of 100gf, it was seen that the number of debonding fibers increased with the increment of the load. A bundle of fibers tended to debond together. In addition, indenting site is also an important factor to decide the number of debonding fibers. The phenomena mentioned above occurred at the place where the fibers distributed densely and touched each other. At the place where fibers distributed separately usually only one fiber debonded when being pushed.

Fibers debonding was very effective to reduce crack initiation. While the fiber was difficult to debond, crack would be introduced on the fiber. Cracks were observed at 50 g-f was applied to the matrix. Cracks usually initiated at the edges of the indenter and propagated along the edges direction in matrix (which were similar with the thick specimens under hardness test in following section). The crack usually deflected at the interface between fiber and coating. Such crack deflection behavior is generally thought to be the reason for SiC composites' toughness.

Crack initiation and propagation were observed during hardness test on matrix. Typically cracks were introduced by 200gf. When hardness tests were carried out in the matrix beside fibers, cracks initiated in matrix. If cracks propagated through coating layer, fibers tended to debond. Therefore, for thin coating specimens, fibers were easy to debond. Different crack behaviors of three kinds of composites with single C-layer with thickness of 290nm, 1900nm and multi-layer with thickness of 3400nm were observed. For composites with the thinnest carbon coating, the cracks were initiated by the indentation partially, debonded multiple fibers until the crack was arrested. In the case of fiber with C-layer thickness of 1900nm, cracks propagated to interface and stopped there without fiber debonding. Similar phenomenon was observed on specimen with multiple layers fibers.

Generally the strength of the matrix is lower than that of the fibers. The primary function of the matrix is to transfer the load to the fibers while the debonding layer prevents catastrophic failure and provides pseudo-plasticity through fibers debonding and pull-out. In the hardness test, thinner coating appeared to produce easy fiber debonding. For improving the toughness of SiC/SiC composite, composites with single layer whose total thickness is below 1000nm will be suggested to be produced for finding the optimum of coating thickness.

For single fiber push-in tests on specimens of ~600μm thick, various debond behaviors were observed. There are two kinds of fibers with a single C-layer or multiple coatings respectively. The indenter load-displacement curve of the single fiber push-in test showed that every fiber had a unique debonding load and the indenter displacement at the maximum load 90gf was likewise unique. Considering the debond load and maximum displacement mentioned the above with the fiber coating thickness together, three figures were drawn out. With increment of the C-layer thickness the displacement of indentor at 90gf increased gradually. From the push-in test on multiple coatings (C, SiC, C) specimens the same tendency was seen. In addition, the load at which fibers began to debond decreased with the increase in the multiple coatings thickness.

As a result of general observation, it appears that thick coatings allowed easier debonding than thin coatings. But the debond load decreased rapidly with increasing coating thickness. If the debond load is too low, the strength of the composite will decrease. Thinner coating has a higher shear strength (ISS) and frictional sliding strength (IFS). When ISS is high, the matrix can transfer load to the high strength fibers. However, if the ISS is very high, or IFS is very high, the fibers will not debond which causes two things to happen: 1) Cracks are not tie-up at the interface and the composite fails at low load. And 2) Unless fiber pull-out and fiber "bridging" occurs the strength at large numbers of fibers are not used. It is found that around coating thickness of 3μm the debonding load is not so low (~70gf) while maximum displacement is not so deep (~2μm). Therefore, a suitable coating thickness should be found in the future work, which has high ISS and makes fiber debond.