An Analysis of Tensile Failure Process of 3D Carbon-Carbon Composites

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Introduction

3D C-C composites possess both the good performance of graphite in bulk at high temperature and exceptionally mechanical properties of composites. 3D C-C is an inhomogeneous material having multiphase structure. Mechanical properties of 3D-C-C depend largely upon the types and conditions of processing, woven structure, properties of fiber bundle, matrix etc. In order to investigate the tensile failure process, the tested specimens were observed by SEM. The pattern of fiber break, which occurred and eventually caused the breakdown of the tensile test specimens is described.

Fracture behavior

The fracture of material may be thought of as an eventual result of a series of complex process caused by stress acted on material. It is possible that the most important parameters effecting the performance of 3D C-C composites are the processing parameters. Because of the variables of manufacture processing procedures, the fracture behavior are different.(1)

Some of typical SEM photographs are described below:

Fig.1. shows a fracture photograph of a failed Z-direction tensile specimen. In many areas of fracture, fiber bundles are found to have been broken and to be completely or partially out of the surrounding matrix. So that fiber failure was not at the same section as apparent matrix failure. It is likely that fiber bundles following failed matrix were pulled-out from matrix materials.

Fig.2. shows that Z-direction fiber bundles failure section was of a rather random nature. That individual fiber within the failed fiber bundles randomly distributed. Delamination and separation were observed in the X-direction bundles perpendicular to the Z-direction. Our experiments showed the tensile strength and strain at failure of specimens having "randomly" or "disoriented" fracture nature are usually higher than that of specimens as shown in Fig.1.

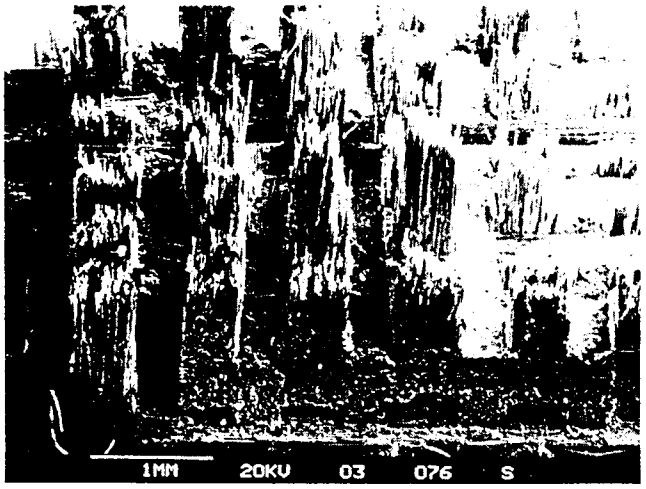

Figure 1.

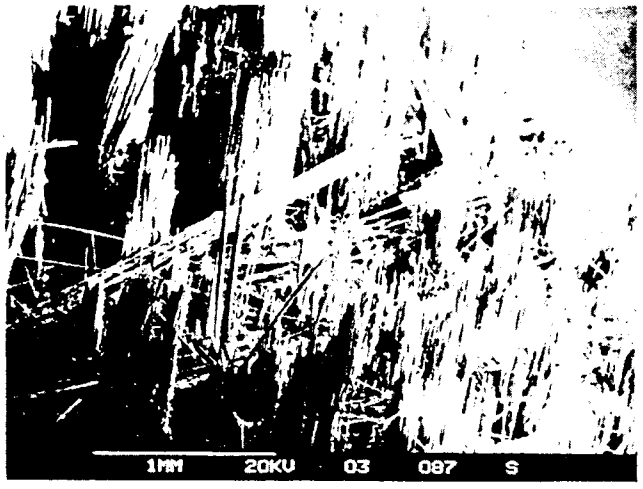

Figure 2.

Fig.3. shows an X-direction tensile fracture of specimen. The failure of X-direction fiber bundles was approximately at the same section as matrix failure. It was shown that the specimens having fracture of this type always have less tensile strength and

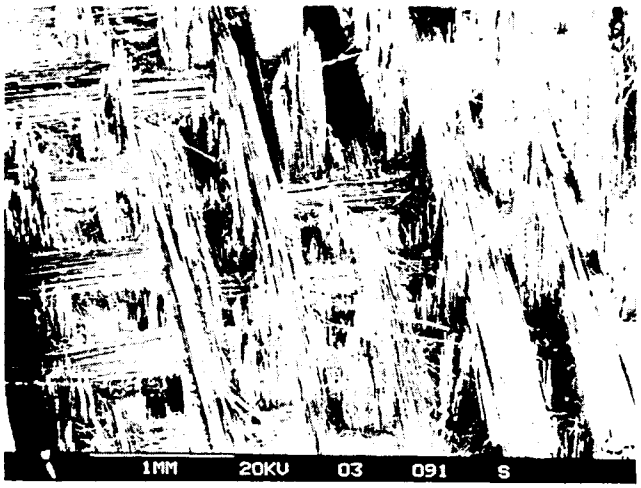

Figure 3.

strain at failure. It should be noted in the specimen of Fig.3. that the fiber volume in the X-direction is less than that in the Z-direction. Since the fibers are the main load-carrying component. There is no surprising that "X-direction" specimens show lower load-carrying ability then "Z-direction".

Fig.4. shows that the broken points of fibers within a bundle were irregular and randomly distributed. It was reported[2] that carbon fibers exhibite a variation in strength with length. In a uniformly strained composite, the weakest fibers break first, and then transfer the load to the remainder. Any fiber which was broken no longer takes its share of the load, it is shared by the remaining fibers within the bundle. So it causes the broken points of fibers to be irregular and it can be shown that such a bundle will not be as strong as the average strength of all the individual fiber multiplied by the number of fibers in the bundle. If one of the bundles became the weakest bundle. It would be broken first and then transfer the load to the other bundles. So it could be thought that cumulative weakening failure of fibers is the most possible cause of 3D C-C specimen tensile failure.

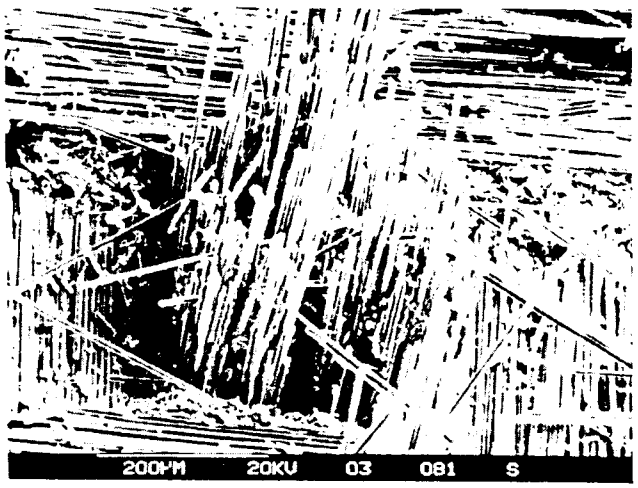

Figure 4.

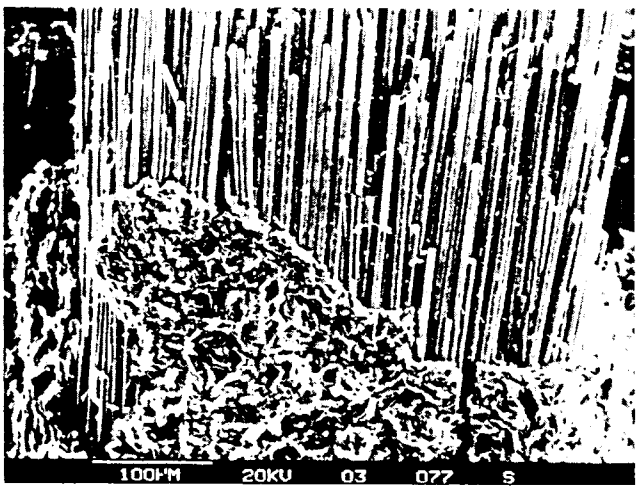

Figure 5.

Fig.5. shows a piece of matrix bonded on a fiber bundle. There was a rather extensive crack network on it. Other piece of matrix which was debonded removed from the bundle. While the fibers within bundle aligned straightly without damage.

Fig.6. shows a pattern of some fibers in the fiber bundle, from it the matrix was broken and separated.

It could be recognized that under the tensile loads, the cracks of specimen started from the matrix regions. When the matrix crack propagates to the fiber surface, stop there, then the crack immediately turn 90° and propagates along the fiber-matrix interface. In the cases of Fig.5. and Fig.6. it causes a partial debonding between the fiber and the matrix. It could be considered tensile strength primarily depends on the strength of the fiber bundle in that direction. Compared with fiber bundle, matrix region and interface between fiber and matrix exhibit relatively low tensile strength. Also there are a large number of crack networks in the matrix region and interface. Hence, as increasing tensile load acted upon the unit cell in a fiber bundle direction, interface will separate. At load levels near those required to cause fiber bundle

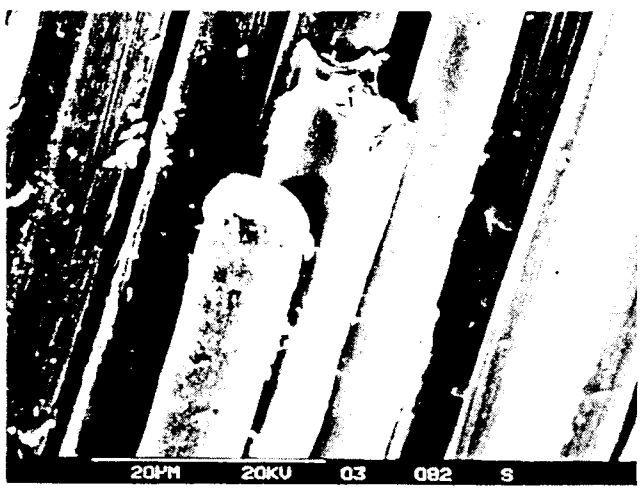

Figure 6.

failure, it is most likely that little or no stress will be carried by any matrix in the unit cell except the fiber bundles in the load direction.

Discussion and conclusion

1. 3D C-C material contains a repeating volume of elements(unit cell). Any unit cell contains three unidirectional fiber bundles(with a 3D orthogonal structure) and two matrix regions. Since the tensile strength and strain at failure of matrix are always much less than those of fiber. So that the crack initiation was found to be in matrix region. The fiber bundles are the main load-carrying component.
2. The failure of fiber bundles undergoes a process of de-bonding, breaking and pulling-out. The fracture of 3D C-C tensile specimen is the results of creation, extension and cumulation of bundles failure under external load. It is shown that cumulative weakening failure is the most probable cause of 3D C-C tensile failure in the principal direction.
3. The studies of the fracture behavior of 3d C-C material indicate that the fracture of such kind of composite is strongly dependent on the methods and parameters of manufacture processing, the fiber-matrix interface, fiber strength and fiber volume fraction. In order to have a full understanding of the mechanism of such kind of composite breakdown, much additional study will have to be undertaken.

References

1. E. FITZER, K.H.GEIGL and W. HUTTNER " The influence of carbon fiber surface treatment on the mechanical properties of C-C composites" Carbon 1979 pp.265-270
2. C.T. ROBUSON, P.H. FRANCIS" Damage initiation in three-dimension composite material" ASTM Stp. 723 May. 1979