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Research Article

Structural Analysis of 3D Carbon-Silicon Carbide Composites

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Abstract

The increasing use of advanced Ceramic Composites in Aircrafts, Automobiles, Missile Systems and Space Structures has been well documented and continuously receiving the wide attention of industry. The structural engineer needs to be familiar with the property of the composite material structures. The behavior of ceramic composite material under impact load plays a pivotal role in designing such structures. An impact test is a test for determining the energy absorbed in fracturing a test piece at high velocity. The impact resistance of a part is, in many applications, a critical measure of service life. In the current work, an attempt is made to present the dynamic behavior of the advanced ceramic composite material, i.e., 3 Dimensional Carbon-Silicon Carbide (3D C-SiC) under the impact, tensile and flexure loads and the mechanical properties, viz., Impact Strength, Tensile Strength and Flexural Strength are determined. In 3Dimensional Geometric Modeling, the spatial orientation of the yarn is explained and the geometric parameters are estimated. 3D C-SiC composite specimen with a fiber volume fraction of 40% is considered and the required mechanical properties are extracted. ANSYS software is used for structural analysis of 3D carbon-silicon carbide composites. The simulated results are checked for its feasibility.

Keywords: *Structural Analysis, Ceramic composites, Carbon-Silicon Carbide, ANSYS.*

1. Introduction

In the last 20 years a great development has occurred in impact machines. The development of reliable mini-transducers has allowed researchers to apply to pendulums and drop weight instruments the same concepts widely applied in the past to static loading machines. With oscilloscopes in the past and by personal computers these days it is possible to measure the force transferred by a striker to a specimen even at high loading rates. This revolution has provided researchers, industries with a new way to characterize material properties during impact. The minimum knowledge required about a material to characterize fracture properties comes from a force – time (or force-displacement) diagram. When performing a test with an instrumented falling weight, it is possible to record the force acting on the specimen throughout the impact. They are finding increasing applications in aerospace, defense and industries. Carbon fiber-reinforced SiC matrix composites are preferred to C-C composites for oxidizing and highly erosive environment. C-SiC composites are used up to 1500^0 C for long durations and up to 2000^0C for short durations. The main applications of C –SiC composites are: nose tips of reusable space vehicles, leading edges of hypersonic vehicles, erosion resistant jet vanes for thrust vectoring of rocket motors and wear resistant brake materials for high speed automobiles. The mechanical and thermal properties of the fiber-reinforced composites can be tailored by adjusting fiber volume fraction and fiber orientation to meet the needs of the application. C-SiC composites retain mechanical strength up to 1700^0 C and have a high thermal conductivity and low thermal expansion and hence excellent thermal shock resistance. There are several methods to fabricate C-SiC composites, such as chemical vapor infiltration (CVI), slurry infiltration combined with hot pressing, polymer-infiltration-pyrolysis (PIP), etc.

2. Methodology

2.1 Simulations of on 3D C-SiC composite specimens

2.1.1 Impact test

The configuration used in analysis is shown in Fig.1 where the striker of nose radius r, traveling at a velocity v, impacts the specimen from a height h, at a distance of 22 mm from V- notch along the length of the specimen. A V-notch of root radius 0.25 mm with included angle of 450 having a depth of 2.54 mm is provided following the ASTM D 256 standards for the

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Izod impact test. The configuration is described conveniently in terms of rectangular coordinates.

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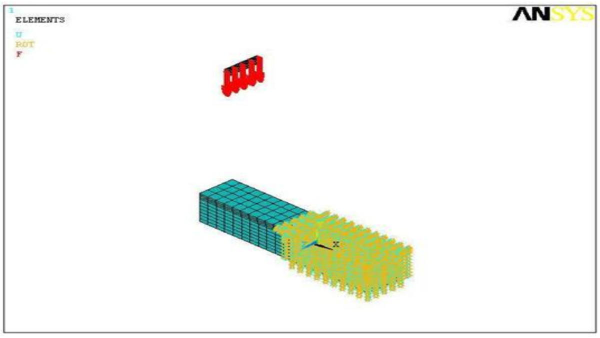

Fig.1 Impact test specimen with loading and boundary conditions

The geometric model is created using ANSYS LS-DYNA software. A 3D structural solid 164 element is used to mesh the geometry of the striker as well as the specimen. Solid 164 element is having 8 nodes with the following degrees of freedom at each node: translations, velocities, and accelerations in the nodal x, y and z directions.

3D solid modeling is used to generate the specimen which then is meshed with solid 164 element shown in Fig.2. A refined mesh is obtained after convergence check with a total number of 880 elements having 1260 nodes as shown in Fig.3.

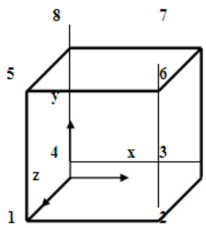

Fig.2 solid 164 element

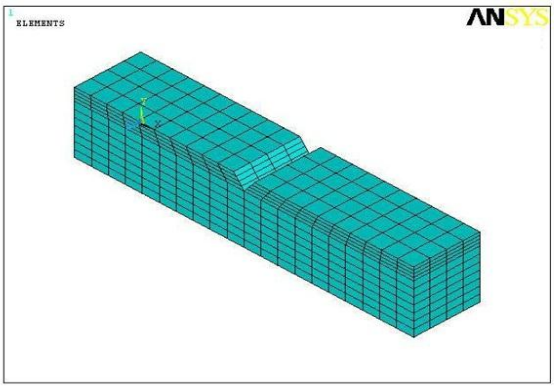

Fig.3 Finite Element model of the notched specimen

The impact process is simulated on the computer by following a transient analysis. The objective of this work is to demonstrate the explicit dynamics using ANSYS LS-DYNA for complex contact dynamics situation which simulates Izod impact test of experimentation.

During the free fall stage, the striker is simply accelerating due to gravity. The analysis is started when the striker is 0.5 m above the specimen in order to save CPU time. The initial velocity of 3 ms-1 is applied to simulate the process. This velocity is an approximation obtained by using V= (2gh) 1/2 where g is acceleration due to gravity and h is displacement. Air friction is assumed to be neglected.

The striker is constrained to have translations in y –direction (1dof). It is restrained to have translations in x, z directions and rotations about x, y, z directions. The deformation obtained from ANSYS is 3.92 mm as shown in Fig.4

The stress distribution is shown in Fig.5. The maximum stress obtained in y-direction is 13.95 MPa. The impact strength obtained for the sample specimen by FE analysis is 27.36 kJ/m^2.

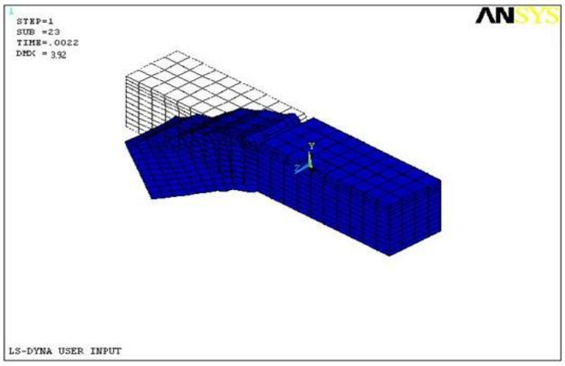

Fig.4 Deformation of the specimen in mm

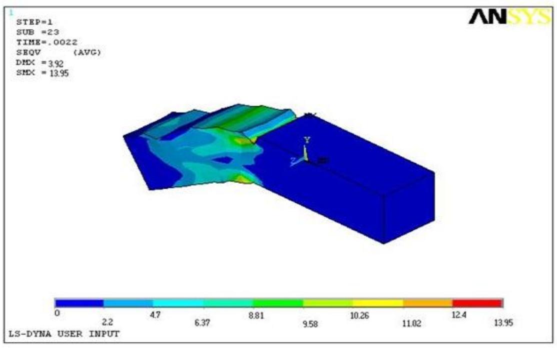

Fig.5 Stress distribution in MPa

2.1.2 Flexural test (ASTM C 1341 standards):

This test method is used for material development, quality control, and material flexural specifications. Although flexural test methods are commonly used to determine design strengths of monolithic advanced ceramics, the use of flexure test data for determining tensile or compressive properties of CFCC materials is strongly discouraged. The non-uniform stress distributions in the flexure test specimen, the dissimilar mechanical behavior in tension and compression for CFCCs, low shear strengths of CFCCs, and anisotropy in fiber architecture all lead to ambiguity in using flexure results for CFCC material design data). Rather, uniaxial-forced tensile and compressive tests are recommended for developing CFCC material design data based on a uniformly stressed test condition.

In this test method, the flexure stress is computed from elastic beam theory with the simplifying assumptions that the material is homogeneous and linearly elastic. This is valid for composites where the principal fiber direction is coincident/transverse with the axis of the beam. These assumptions are necessary to calculate a flexural strength value, but limit the application to comparative type testing such as used for material development, quality control, and flexure specifications. Such comparative testing requires consistent and standardized test conditions, that is, test specimen geometry/thickness, strain rates, and atmospheric/test conditions.

This test method covers the determination of flexural properties of continuous fiber-reinforced ceramic composites in the form of rectangular bars formed directly or cut from sheets, plates, or molded shapes. Three test geometries are described as follows: Test Geometry I—A three-point loading system utilizing center point force application on a simply supported beam.

Test Geometry IIA—A four-point loading system utilizing two force application points equally spaced from their adjacent support points with a distance between force application points of one half of the support span.

Test Geometry IIB—A four-point loading system utilizing two force application points equally spaced from their adjacent support points with a distance between force application points of one third of the support span.

This test method applies primarily to all advanced ceramic matrix composites with continuous fiber reinforcement: uni-directional (1-D), bi-directional (2-D), tri-directional (3-D), and other continuous fiber architectures. In addition, this test method may also be used with glass (amorphous) matrix composites with continuous fiber reinforcement. However, flexural strength cannot be determined for those materials that do not break or fail by tension or compression in the outer fibers. This test method does not directly address discontinuous fiber-reinforced, whisker-reinforced, or particulate-reinforced ceramics. Those types of ceramic matrix composites are better tested in flexure using Test Methods.

The specimen is held in the testing machine as a simply supported beam and load is gradually applied at the centre. When the applied load reaches ultimate value the specimen breaks and subsequently the load falls to zero.

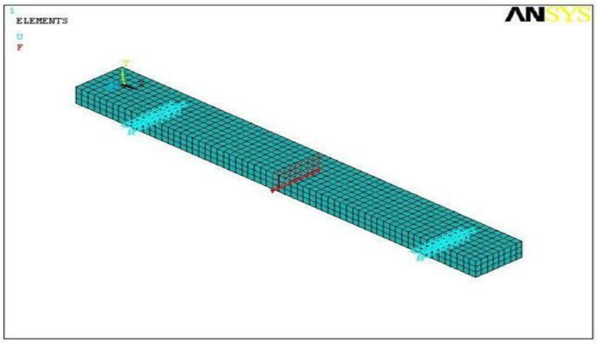

Fig.6 Flexural test specimen with loading and boundary conditions

The finite element model is generated using ANSYS software. A 3D solid 45 brick element with 8 nodes is used to mesh the geometry of the specimen. Solid 45 element has 3 dofs. A refined mesh is obtained with 1560 elements and 2376 nodes which are shown in Fig.6

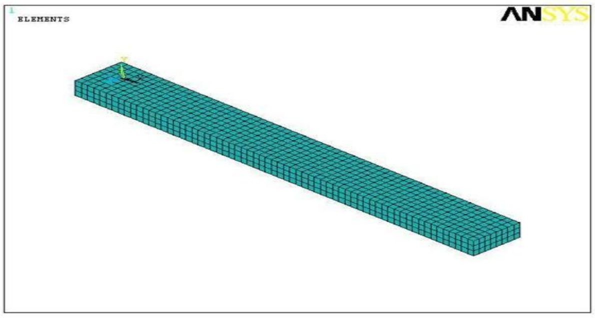

Fig.7 Finite Element model of the test specimen

The computer simulations of flexural test are performed by choosing the ultimate loads recorded in the test. The deformation obtained by computer simulation of flexural test is 2.58 mm as shown in Fig.7.

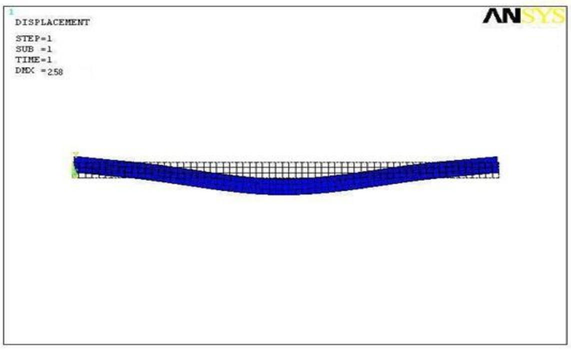

Fig.8 Deformation of the flexural specimen in mm

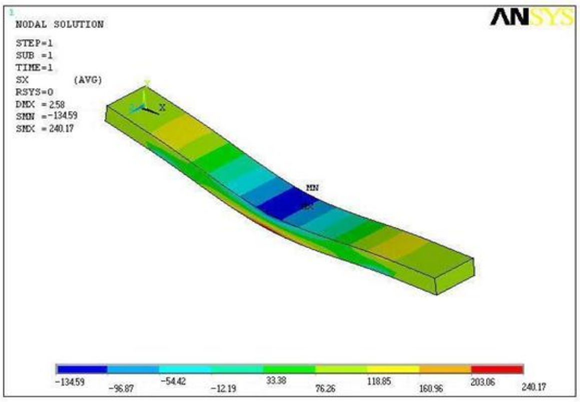

Fig.9 Flexural stress distribution in MPa

From Fig.9.The maximum flexural strength obtained by computer analysis is 240.17 MPa.

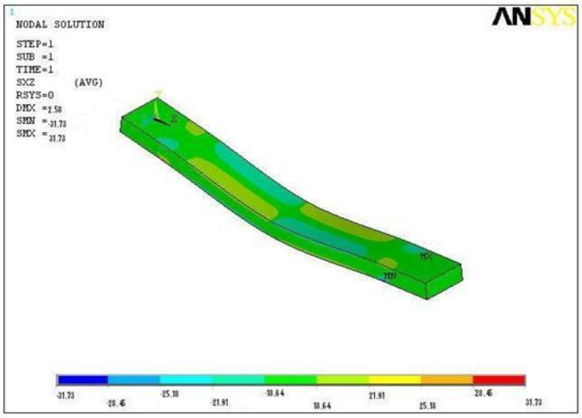

Fig.10 Shear stress distribution in MPa

From Fig.10, The maximum shear stress obtained from this analysis is observed to be 31.73 MPa

2.1.3 Tensile test (ASTM C 1275 standards):

This test method covers the determination of tensile behavior including tensile strength and stress-strain response under monotonic uniaxial loading of continuous fiber-reinforced advanced ceramics at ambient temperature. This test method addresses, but is not restricted to, various suggested test specimen geometries as listed in the appendix. In addition, test specimen fabrication methods, testing modes (force, displacement, or strain control), testing rates (force rate, stress rate, displacement rate, or strain rate), allowable bending, and data collection and reporting procedures are addressed. Note that tensile strength as used in this test method refers to the tensile strength obtained under monotonic uniaxial loading where monotonic refers to a continuous nonstop test rate with no reversals from test initiation to final fracture.

This test method applies primarily to all advanced ceramic matrix composites with continuous fiber reinforcement: uni-directional (1-D), bi-directional (2-D), and tri-directional (3-D). In addition, this test method may also be used with glass (amorphous) matrix composites with 1-D, 2-D, and 3-D continuous fiber reinforcement. This test method does not address directly discontinuous fiber-reinforced, whisker-reinforced or particulate-reinforced ceramics, although the test methods detailed here may be equally applicable to these composites. Values expressed in this test method are in accordance with the International System of Units (SI) and this standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

The loading and boundary conditions are shown in Fig.11. The specimen is fixed in the testing machine and the movable jaw is adjusted for the gauge length of 25 mm. The tensile load is gradually applied till the specimen is broken at the average max. values of 1.26-1.62 kN. The load then falls to zero.

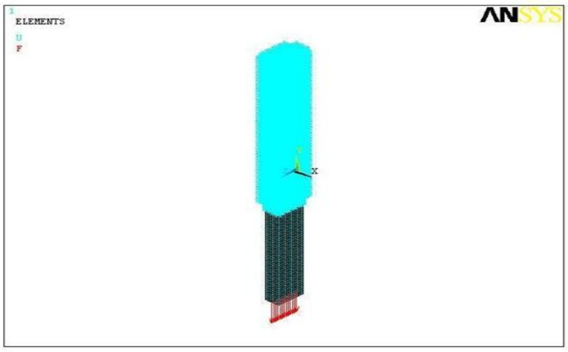

Fig .11 Tensile test specimen with loading and boundary conditions

The Finite Element model is created by using ANSYS 11.0 software. The specimen is meshed with the 3D solid 45 brick element which has 3 dofs. Fig.11 shows the finite element model of the tensile test specimen obtained with 9000 elements and 11466 nodes.

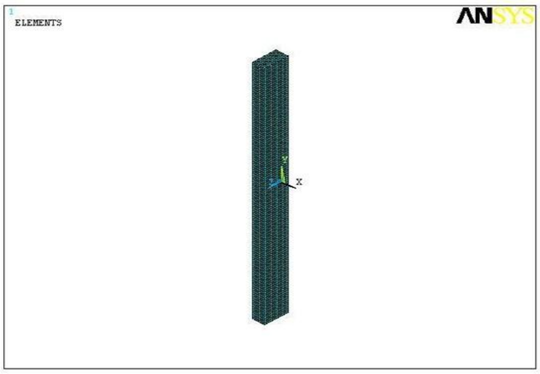

Fig.12 Finite Element model of the tensile test specimen

The test process is simulated on the computer by running ANSYS program. One end of the specimen is fully restrained and the other end is constrained to have translations along the principal material direction. The computer simulations are performed by applying a gradual load. The analysis is completed when the load reaches a maximum value of 1.26-1.62 kN. The deformation obtained in ANSYS is 0.23 mm.

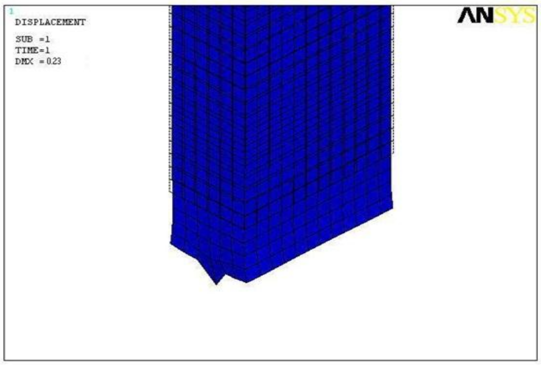

Fig.13 Deformation of tensile test specimen in mm

The tensile strength distribution for the specimen is shown in Fig.14. The tensile strength obtained for specimen from this analysis is 71.735 MPa.

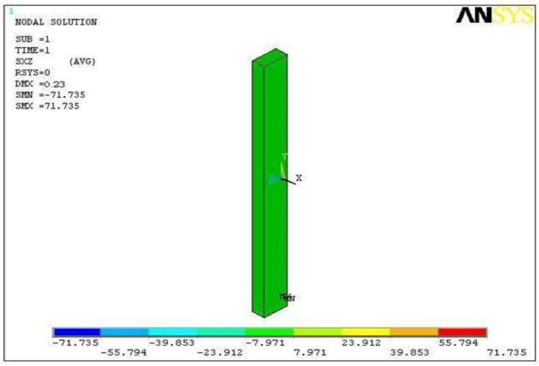

Fig.14 Tensile strength distribution in MPa

Results and Discussions

First of all, when the striker touches the specimen the impact point is immediately accelerated from zero velocity to the initial velocity of the striker.

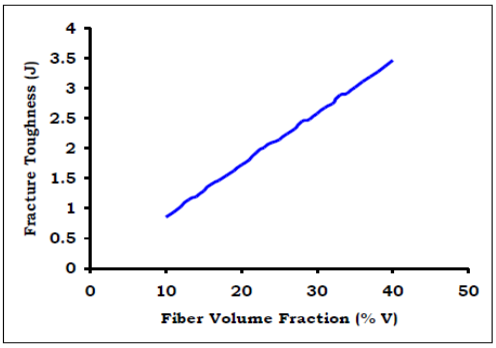

Fig .15 Variation of Fracture Toughness with Fiber Volume Fraction

This instantaneous acceleration, for the Newton's second law, causes a first peak of force named inertial peak (because of the inertial nature of this phenomenon). After this, strong oscillation force increases linearly. At low displacements, in fact any material can be considered elastic so that force is proportional to displacement (and therefore to time, if impact energy is high). The absorbed energy is a measure of material strength and the ductility can be graphically represented as the area beneath the load-displacement curve.It is obvious that 3D C-SiC composite materials exhibit an excellent impact damage tolerance because of Z-direction fibers. The measured properties of 3D C – SiC composites are compared with the properties of 2D C-SiC.

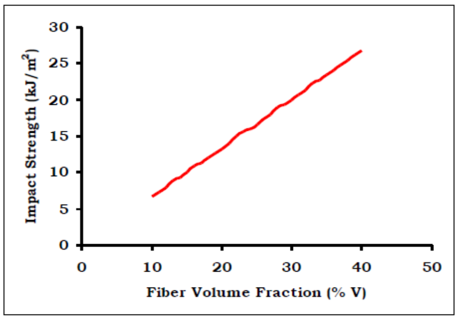

Fig .16 Variation of Impact Strength with Fiber Volume Fraction

Table 1 Comparison of mechanical properties of 2D C–SiC composites (From literature) with FE results of 3D C-SiC specimen

Properties	2D C-SiC (LSI)	3D C-SiC (LSI)
	From Literature	From FE analysis
Fiber Volume (Vol. %)	40-42	40
Density (g/cc)	2.4	2.2-2.4
Flexural Strength (MPa)	180-200	210-230
Tensile Strength (MPa)	80-90	70-90
Young's Modulus (GPa)	25-30	32-35
Strain to Failure (%)	0.25-0.35	0.20-0.28
Impact Strength (kJ / m2)	20-21	26-27

The average result of flexural strength is observed to be 220 MPa. The variation of failure behavior of composites is caused by alteration of the interfacial bonding between fiber and matrix. The tensile stress within the interfacial phase along the fiber radial direction is generated after the composite material is cooled down from the infiltration temperature to room temperature.

Conclusions

The important conclusions drawn from the present work are:

1. The SEM micrographs reveal the uniformity of siliconisation and relatively less amount of unreacted silicon and carbon in the final composites.
2. In 3D geometric modeling, it is explained how the fiber volume fraction is increasing when crimp angle is increased gradually.
3. By using the three dimensional geometric analysis, the orientation of any yarn in space in a unit cell; and the three dimensional geometry of the reinforcing fiber for a woven fiber composite have been completely determined.
4. The mechanical properties of 3D C–SiC composites are determined. When fiber volume fraction is increased, fracture toughness and impact strength are increased.
5. The maximum shear stress obtained from Finite Element analysis is observed to be 31.73 MPa.
6. The tensile strength obtained from the FE analysis is 71.735 MPa.

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