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Evaluation of Physical and Mechanical Properties of 3-D Orthogonal Non Woven Carbon – Carbon Composites - A Comparative Study

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Abstract

The usage of Carbon-Carbon composites in Aerospace has increased rapidly over the past several years. The rapid strides in increase are primarily the result of advent of advanced materials with excellent mechanical properties combined with light weight; corrosion resistance and other achievement of desired properties are the allied benefits. 3-D Multidirectionally Reinforced composites are candidate materials for such type of applications. Few Carbon fibre preforms of 3-D orthogonal non-woven are made with different Fibre Architecture like weave configuration, fine, course unit cell dimensions and maintaining selected distribution of fibre volume fraction in all the three directions. These are further elaborated and their configurations are indicated in this paper. Carbon matrix system used to infiltrate these two preforms. To understand the influence of preform structure over the 3-D composite structures these are tested for physical and mechanical properties i.e., preform fibre volume fractions, density, Tensile, Flexural, Compressive, and Inter-Laminar Shear Strength were evaluated. A comparative analysis of the test values is presented and results are discussed. Some findings and inferences are drawn from the output data of results. These are interpreted and presented.

Keywords: 3D Carbon- Carbon Multidirectionally, unit cell, fibre volume fraction, ILSS Fibre Architecture.

I. INTRODUCTION

The increasing trend in using 3-D composites in Aerospace and Defense research calls for a complete understanding of 3-D composites and their behavior at different test conditions are yet to be established. Limited data on this subject and the cost involved in making these 3-D composites are the other drawback. An attempt is made to evaluate 3-D orthogonally woven carbon-carbon composites with variation in the preform geometries. 3-D preforms are developed with different preform configurations with varying preform geometries and these preforms are tested for Mechanical properties.

A. Development of fibre preforms on 3-D orthogonal co-ordinates.

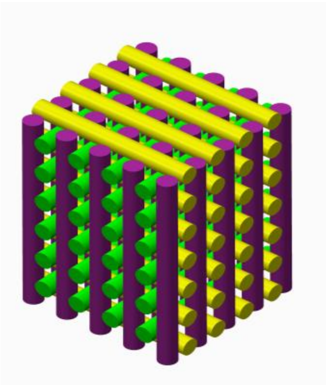


Figure 1: 3-D construction

Figure 1. Explains the basic construction of a 3-D preform geometry. A Three Directional preforming technology offers capability to position the fibres in three directions with specified amount of volumes to meet the design loads acting on the composite structure.

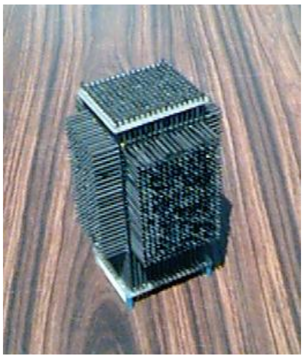


Figure 2: 3-D with carbon rods

A 3-D orthogonal construction as shown in the figure.2 Fibre bundles are sited on Cartesian co-ordinates in straight form and in the non-woven fashion. Figure 2. is a 3-D preform made of carbon fibre pultruded rods with epoxy resin. Here fibre acts as a

reinforcement and epoxy resin system acts as binder as well as matrix of the final composite. Dia 2.0 mm rods are taken and they are positioned in all three directions with the help of a fixture as shown in the fixture.
During preforming process epoxy resin used as the binder and void filler. This is one of the highly practiced process in the composite industry and it has its own limitations.

Figure. 3: 3-D Carbon fibre preform

Figure 3. Shows a preform made through complete dry fibre weaving process. It is a orthogonal non-woven process and is a laborious process. Several preforms are made through this dry weaving process and preforms are densified followed by Carbon-Carbon process.

II. MATERIAL AND METHODOLOGY

A. 3-D Preform Terminology

Figure .4 explaining the arrangement of x, y, z yarn bundles in a unit cell of 3-D preform. And it also presents the terminology for preform yarn bundle spacing

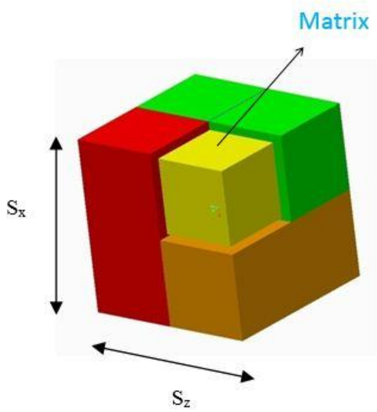


Figure 4: 3-D Preform Unit Cell

S_x, S_y, S_z are the center distances of X, Y, Z yarn bundles. Sx and Sy are equal in centre distances and the volume of the preform unit cell is $S_xS_z^2$ is the measure of preform fineness. V_{fz}, V_{fx} are the yarn distribution volume fractions in those directions. V_{ft} is the total fibre volume fraction in the 3-D preform.

The yarn bundle sizing i.e., 3K, 6K, 12K, bundle spacings S_x , S_y, S_z , Yarn packing efficiency and the fibre volume fraction in each direction characterizes the 3-D preform design. Preforms made of 3K gives the finest weave. 3-D preforms are identified with weave configuration as an example 1,1,1 is 3-D preform with balanced weave with one yarn bundle in all three sites. In 1,1,2 two yarn bundles are positioned at z site. Table 1. Gives the complete picture about three preforms developed . The fibre used to develop these preforms is T_{300} Asahi Nippon 6K .

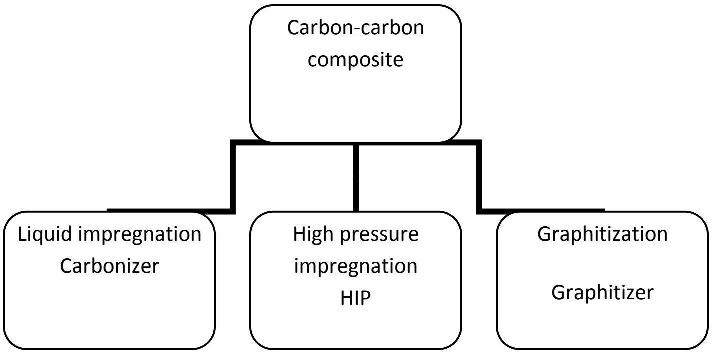
Table 1: 3-D orthogonal non-woven Preform specifications

3-D Preform construction	**1, 1, 2**	**1, 1, 4**	**2, 2, 4**
Fibre used T_{300}	6K	6K	6k
Unit cell size Sz mm	2.18	2.12	2.37
Unit cell size Sx mm	0.38	0.514	0.92
Unit cell volume mm^3	1.806	2.310	5.167
Reinforcement Nx , Ny	2523	2754	2136
Reinforcement Nz	3621	5340	5503
Fibre volume fraction Vfx	14 %	10.6%	10.5%
Fibre volume fraction Vfz	9.7%	20.5%	16.45%
Total volume fraction Vft	37.7%	41.7%	37.3%
Packing efficiency	37.6%	41.8%	37.5%
Preform density gm/cc	0.678	0.752	0.676

B. Densification process of 3-D preforms:

All the above three preforms are converted into Carbon-Carbon composites through densification process. Many factors are considered before selecting the matrix precursor. Features related to preform are size , shape, yarn type, weave geometry, pore size and the distribution of pore, pore channels connected , fibre volume fraction, dry woven are rods assembly. Figure 5. Shows the densification process. Density of final composite is aimed for 1.72 gm/cc and above.

Coal tar pitch being used for preform densification process. This is a cyclic process and taken about 16 weeks of time.



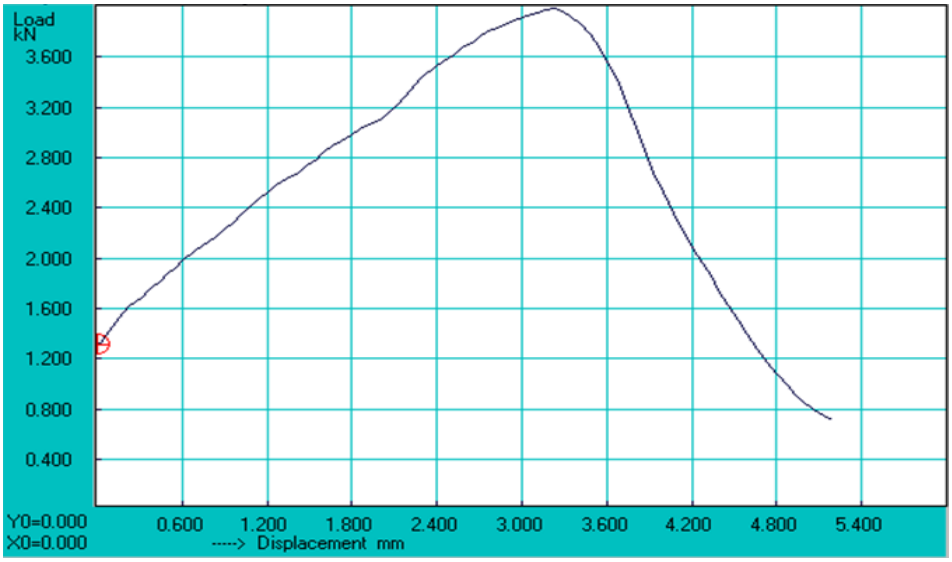
When samples are reached the desired density as a Carbon-Carbon composite, processing has completed.

III. RESULTS AND TABLES

Testing of 3-D Carbon-Carbon composites.

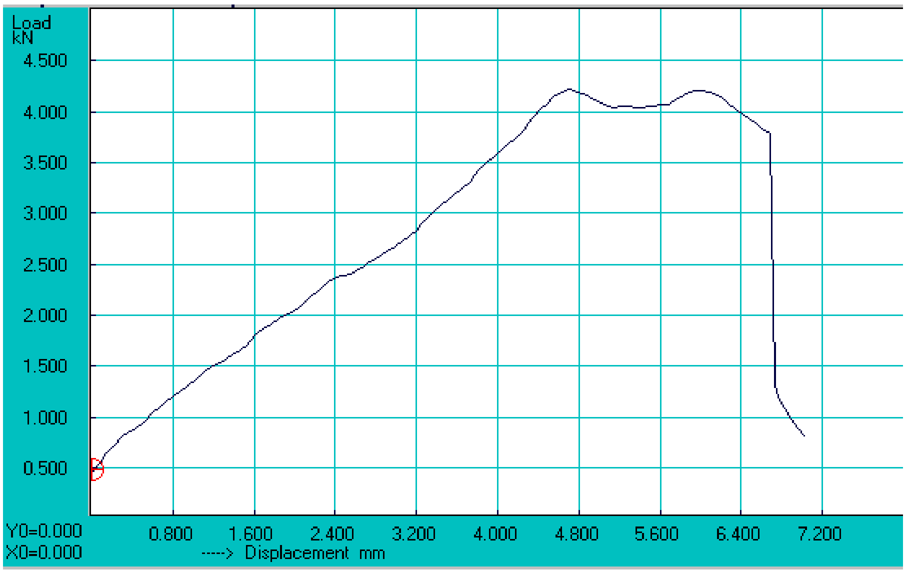
Samples are tested for Tensile, Flexural and Compressive properties. Test samples are prepared as per ASTM test standards and universal testing machine is used for testing these samples. Test samples are taken from X and Z directions.

A. Tensile testing



Graph 1: 3-D sample 1,1,4 tested for Tensile strength in X direction

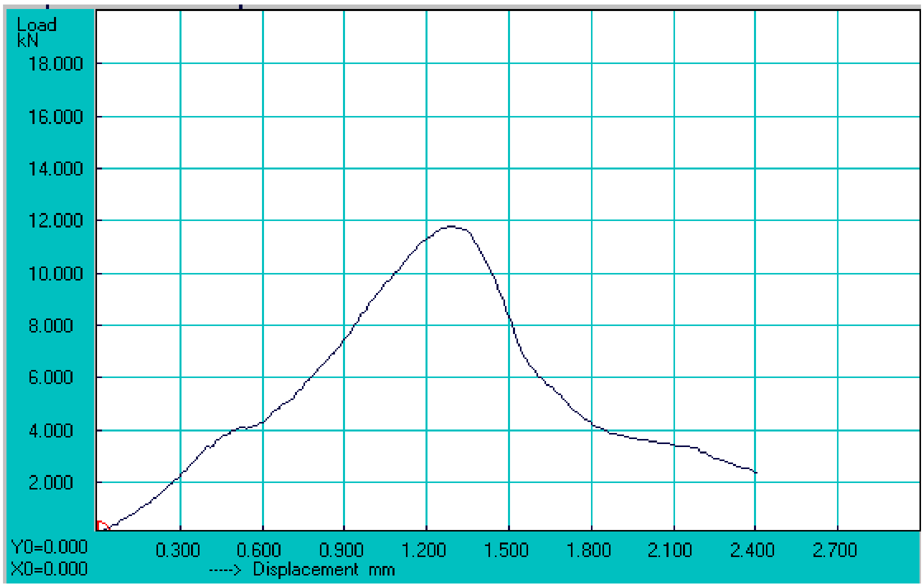
Graph. 1 shows the load v_s displacement diagram for test sample in X direction.



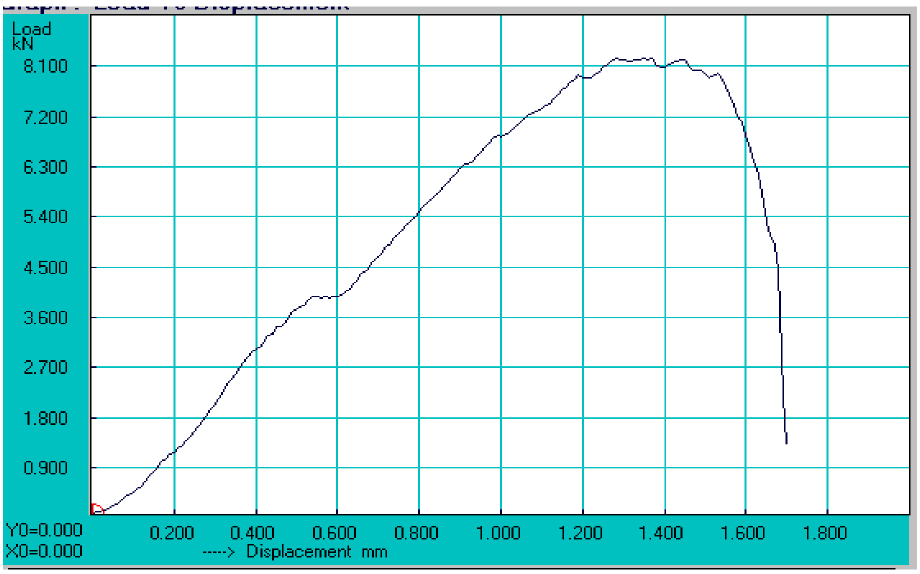
Graph 2: 3-D sample 1,1,4 tested for Tensile strength in Z direction

Graph. 2 shows the load v_s displacement diagram for test sample in z direction.

B. Compressive Testing



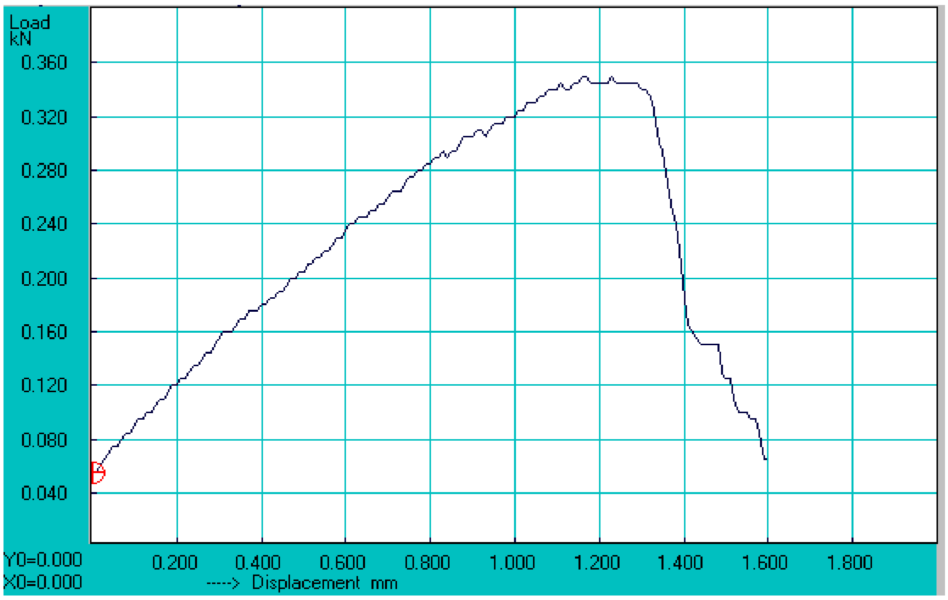
Graph 3: 3-D sample 1,1,4 tested for Compressive strength in X direction



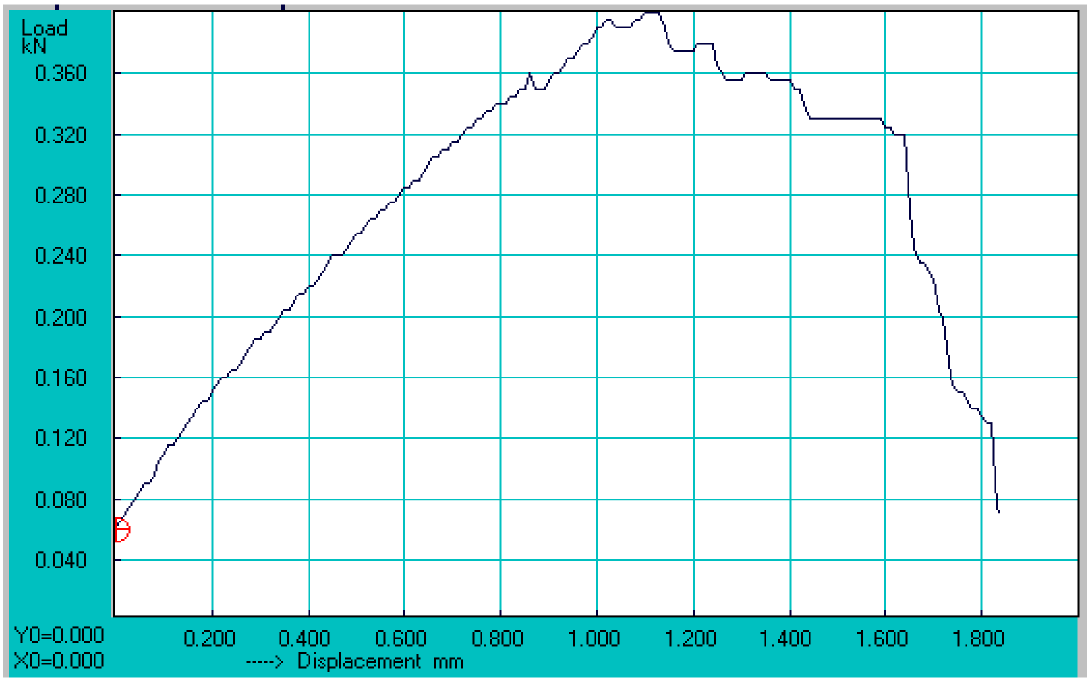
Graph 4: 3-D sample 1,1,4 tested for Compressive strength in Z direction

Graphs 3&4 show the compressive strength of the samples

C. Flexural Testing



Graph 5: 3-D sample 1,1,4 tested for Flexural strength in X direction



Graph 6: 3-D sample 1,1,4 tested for Flexural strength in z direction

Graphs 5&6 show the Flexural strength of the 1,1,4 sample.

Figure 5: 3-D sample Tensile failure

Figure 5. shows the 3-D Carbon-Carbon test Sample in Z direction failed at Tensile strength. The test results of different 3-d configurations are discussed at the Table 2.

Table 2: 3-D carbon-carbon test results.

3-D C/C construction	**1, 1, 2 Mpa**	**1, 1, 4 Mpa**	**2, 2, 4 Mpa**
Tensile Strength in X dir	48	47	38
Tensile Strength in Z dir	98	81	133
Compressive Strength in X dir	83	82	87
Compres Strength in Z dir	81	106	70
Flexural Strength in X dir	35	35	61
Flexural Strength in Z dir	37	40	109
Unit cell volume mm^3	1.806	2.310	5.167
Total volume fraction V_{ft}	37.7%	41.7%	37.3%
Preform density gm/cc	0.678	0.752	0.676

Table 2. Explains the Tensile, Compressive, Flexural test values of 3-D Carbon-Carbon composites with different constructions. It explains strength values in both X & Y directions.

IV. CONCLUSION

It is observed that Total fibre content is more in coarse weave when compared with fine weave. As a solid square rods reinforcement we can pack fiber content up to 75.0% in a 3-D preform. Tensile strength in X direction in both 1,1,2 and 1,1,4 are same and in Z direction 1,1,2 exhibiting more strength. Compressive strength is high in Z direction

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