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# Relative Performance Analysis of Multidirectionally Reinforced Composites in Aerospace Applications

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*Abstract*—**Comparative analysis and the present research carried on Multidirectionally Reinforced Composites show that they can be potential and prospective candidate materials for Aerospace applications as they have superior specific properties compared to the traditional 2-D laminate composites. To overcome the shortcomings of 2-D Composites various types of Multidirectionally reinforced composites (3-D) incorporating fibres in thickness direction have been developed and they are free from delamination and demonstrate to be better damage tolerant materials. They offer the promise of being tailored to meet directional property requirements of an end use item. Mechanical, physical & thermal properties of composites can be tailored by the design of preform parameters such as fibre, matrix properties, fibre orientation, fibre volume fraction in each direction, packing efficiency, pore size, pore distribution, unit cell volume and the Fibre Architecture. This paper addresses the various types of Multi-Directional preform manufacturing processes and the preform design. A comparative analysis of UD, 2D, 3D & 4D orthogonal non woven preforms is conducted and the findings are revealed in this paper. The inferences and conclusions derived are discussed with reference to Aerospace applications.**

***Keywords***—**Multidirectionally Reinforced Composites, Preform, 3D orthogonal non woven preforms, unit cell, 4D Hexagonal, Fibre Architecture, Fibre Volume fractions, Void distribution**

## I. Introduction

The most attractive feature of “Multi-directionally Reinforced Composite” is the additional reinforcement in the through thickness direction, that makes the composite virtually delamination free. And multi-directionally reinforced fibre preform technology provides mechanism to provide tailored composites to meet desired properties viz., physical, mechanical and thermal properties of an end use item [1]. It has been shown by research studies that the properties of these composite products depend to a greater extent on the preform Fibre Architecture. Preform fibre architecture can be classified into four categories, discrete, unidirectional ID, planner inter-related 2D and fully integrated 3D [2]. The example of discrete system is fibre mats, tape-lay-up as UD, fabric lay-up 2D and fourth category is 3D preform where the fibres are oriented in various in-plane and out of plane directions. 3D fibre architecture is further classified into wovens, orthogonally non-wovens, braiding etc. In this paper we focus on 3D orthogonal non-wovens. The simplest type of multidirectional structure is a three-directional (3D) orthogonal construction. As shown in figure 1. a 3D preform consists of fibre bundles positioned on Cartesian co-ordinates. i.e., preforms are developed with yarns oriented in the X, Y and Z directions [3]. 4-D Hexagonal structure is another type of preform where yarns are oriented in four directions. A 4-D structure with U, V, W directions of reinforcement perpendicular to Z direction is as shown in figure.2. In order to enhance composite properties between the planes of reinforcement of 3-D orthogonal structures diagonal yarns are introduced into the preform. The 7D structures may be two types, 3 orthogonal directions plus 4 diagonal directions of reinforcement across the corners or across sides of a block. 3-D cylindrical shapes or conical shapes are woven with yarn reinforcement in the radial, axial, and circumferential directions. A Combination of the 3-D base structure,diagonals across the faces and diagonals across the corners produces a more isotropic woven structure.

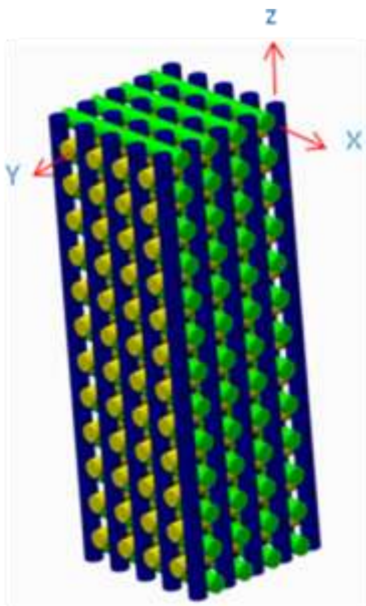


Fig: 1. 3-D Orthogonal construction

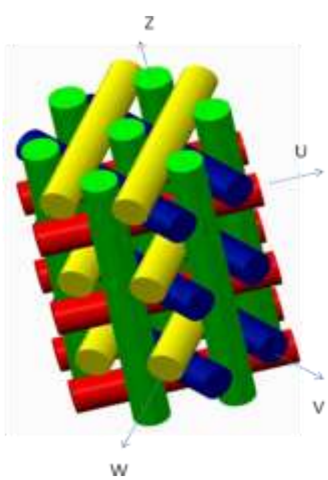


Fig: 2. 4-D Hexagonal construction

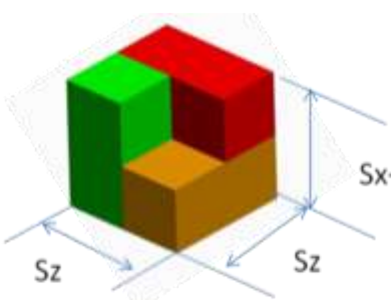


Fig: 3. 3-D Unit cell

Figure: 3 illustrate the 3-D preform unit cell and the terminology for preform yarn spacing. Fineness of preform can be qualified by a parameter "Unit Cell" volume. i.e., $V_{uc} = S_x S_z S_z$ reinforcement in each direction and fibre volume fractions in $V_{fx}$, $V_{fy}$,$V_{fz}$ and total fibre volume fraction in each direction $V_{ft}$ can be derived from the unit cell geometry

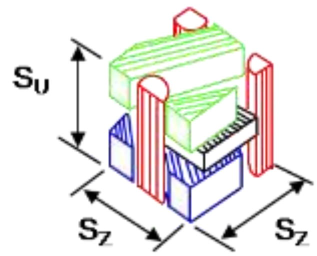


Fig: 4. 4-D unit cell

Figure: 4 illustrates 4-D Hexagonal array preform unit cell. Unit cell in 3-D construction is a cube shape where as in 4-D it is a trapezoidal.

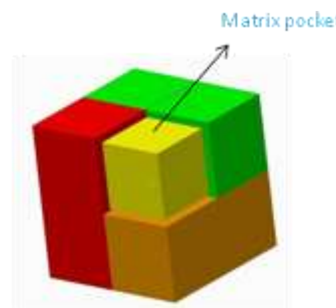


Fig:5. 3-D void and matrix pocket

Figure: 5 shows the matrix pocket shape and it's position in a 3-D construction. One of the most important design parameter is the size and distribution of pocket. The infiltration of a large void packet with matrix or resin will result in localized shrinkage during cure. Small and well dispersed matrix pockets are easier to fill with matrix and can avoid localized shrinkage during curing cycles [4].

# II. Fabrication methods

Various manufacturing techniques have been used to make the multidirectional preforms. One of the most versatile and widely used 3-D performing approaches is dry weaving process. In the process initially all the 'Z' fibre bundles will be positioned using loom plates and the fibre bundles in X-Y directions will be laid between the corridors of the 'Z' spacings.

Fig: 6 Shows the dry weaving process

Fig: 7 3D, 4D woven performs

Figure. 6 . 6 & 7 shows the dry weaving process and the woven performs. Another preforming process is fibre rods assembly into desired directions and bonding them with binder. Figure. 8&9 demonstrates the 3-D and 4-D performs made of carbon fibre pultruded rods.

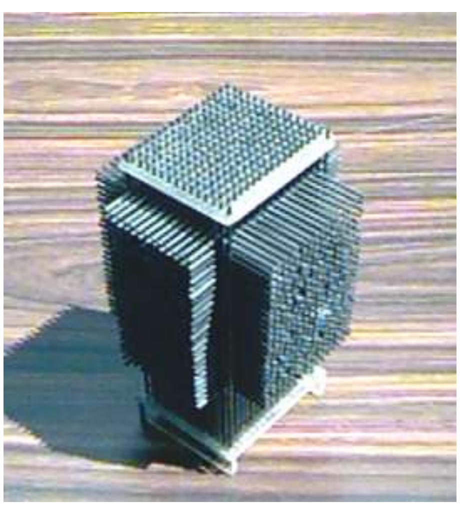

Fig: 8 3-D carbon fibre rods assembly

Fig: 9 4-D carbon fibre rods assembly

# III. Evaluation of mechanical properties

To understand the 3D and 4D structures and to get test data for design inputs 1D, 2D, 3D 4D performs are made with Dia 1.99 mm carbon-epoxy pultruded rods maintaining the basic weave configurations and unit cell dimensions. T300-6K carbon fibre is used to made the carbon fibre-epoxy pultruded roads. All the four performs are densified with epoxy resin system through resin transfer moulding process [5]. LY556 and HV 951 epoxy resin system is used to infiltrate these preforms. The significant and salient feature in this analysis of test data has the specialty that all the configurations are in the rod form. Also it may be stated here that 2D test samples here are unconventional unlike the general fabric laminates used. Carbon fibre pultruded rods of are tested and the results obtained are 1222 Mpa as tensile strength, 149 Gpa as tensile modulus, 0.82 % is the fibre content in each rod. 3-D and 4-D Carbon fibre dry woven performs are densified into Carbon-Carbon composites as shown at fig.10 [6].

Fig: 10. 3-D and 4-D Carbon-Carbon densified blocks

Based on the unit cell dimensions preform packing efficiencies in-terms of fibre volume fractions $V_{fx}$, $V_{fy}$, $V_{f2}$ and $V_{f2}$ are derived. Table 1. Shows the fibre volume fractions in 2D, 3D, 4D preforms and compares mechanical properties of all these structures.

Table 1 Mechanical Properties of Multidirectional Carbon-Epoxy Composite.

| Property | 1D | 2D | 3D | 4D |
|---|---|---|---|---|
| Fibre packing Vfz | 62.0 | 31.0 | 15.67 | 13.51 |
| Fibre packing Vfx , Vfy | - | 31.0 | 15.67 | |
| Fibre packing Vfu ,v,w | - | - | - | 9.10 |
| Fibre packing Vft | 62.0 | 62.0 | 47.00 | 40.84 |
| Tensile strength Mpa | 607 | 258 | 106 | 95 |
| Tensile modulus Gpa | 100 | 44 | 28 | 17 |
| Ultimate failure strain | 7000 | 6500 | 3500 | 4500 |
| Compressive strength Mpa | 326.7 | 232.9 | 110.7 | 73.8 |
| ILSS Mpa | 77 | 19 | 18 | 12 |
| Flexural strength Mpa | 658 | 210 | 253 | 116 |
| Flexural modulus Gpa | 102 | 46 | 13 | 10 |
| Density | 1.56 | 1.36 | 1.22 | 1.03 |

Test samples are prepared as per ASTM standards and using Instron Universal Testing Machine Tensile, Flexural, compressive and ILSS Interlaminar shear strength properties are tested. Figures 11,12,13 illustrates the tensile behavior of 2D,3D,4D specimens and Graph no.14 shows the ILSS Tensile and flextural values obtained for these specimens.

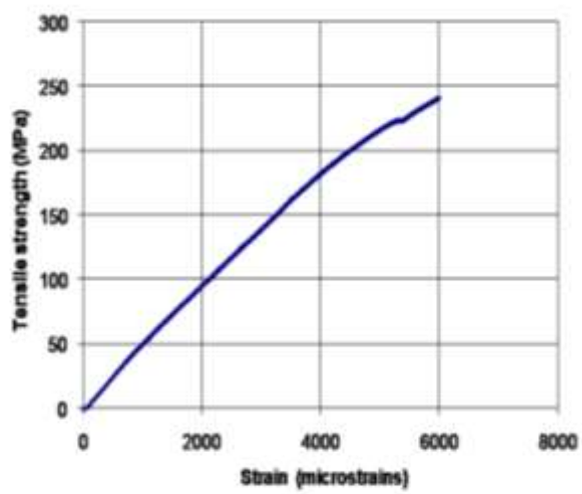


Fig: 11. Tensile Strength Vs Strain of 2-D Carbon-Epoxy

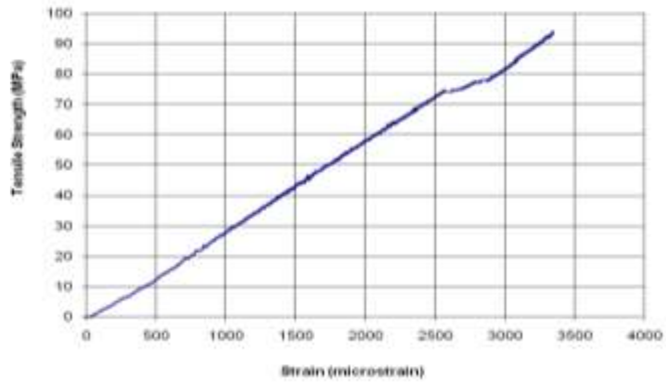


Fig: 12. Tensile Strength Vs Strain of 3-D Carbon-Epoxy

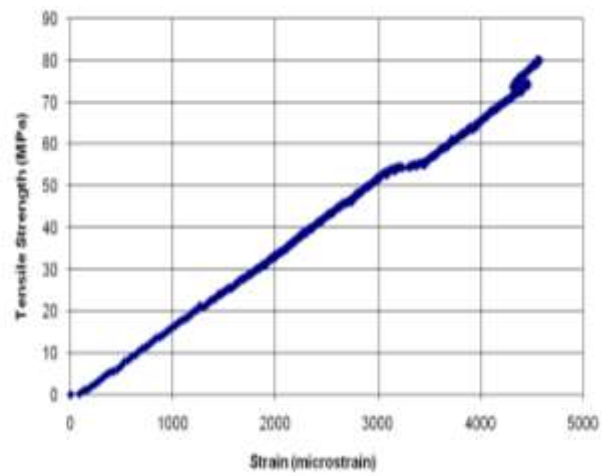


Fig: 13. Tensile Strength Vs Strain of 4-D Carbon-Epoxy

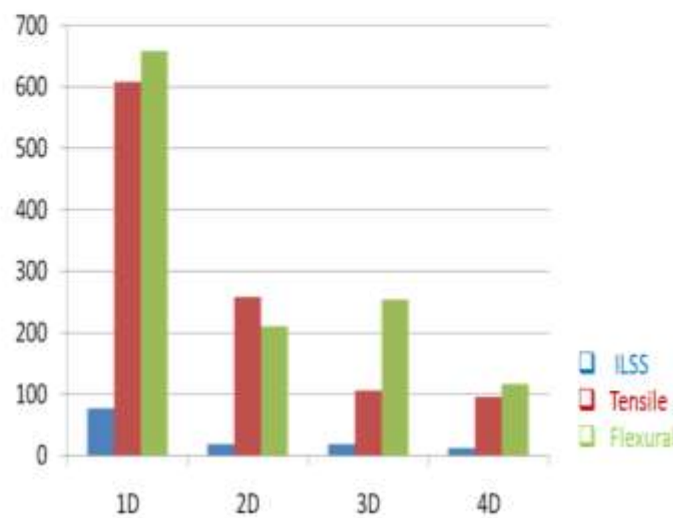


Fig: 14. Mechanical Properties of 1D, 2D, 3D, 4D Carbon-Epoxy

# IV. Conclusions:

The significant and salient feature in these analyses of test data has the specialty that all the four preform configurations 1D, 2D, 3D, 4D are in the rod form. Also it may be stated here that 2D test samples here are unconventional unlike the familiar fabric laminates. Some notable inferences and interpretations have also emerged from these data of results. Total fibre volume fraction in 4D is less in comparison with 3D. This observation can be attributed to the reason that fibre volume is distributed in four directions and also due to the large size of void distributions. Thereby it is observed that mechanical properties of the 3D structures are superior to 4D structures. 4-D offers a more isotropic substrate than the 3- D. Interlaminar Shear Strength (ILSS) values are improved in all directions in 3D and 4D structures when seen in contrast to 2-D and U-D. Multidirectionally Reinforced structures improve the planar properties in all orientations. Hence it can be inferred that Fibre architecture has prominent influences on final mission critical properties of any composite structure.

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