Study of Mechanical Properties of the Carbon Fiber Reinforced Composite with Built-In Hole in 3-Dimensional Noobed Woven Fabric

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Abstract

Fiber reinforced composite has the wide range of application in aviation industry, defense, marine engineering and many more. These composite are used in laminate form largely and in few 3 Dimensional woven fabric composite. 3D Orthogonal weaving is the NOOBED method which is the acronym for Non-Interlaced Orthogonally Orienting and Binding of the yarns. This structure is free from crimp in the yarn structure in the 3D fabric and thus it contributes to the strength of the composite material. These fiber reinforced composite are always assembled with some other material like metal or aluminum using nuts and bolts. For joining these through nuts bolts holes are drilled in the FRC disrupting the continuity of the yarn in the fabric and hence largely affecting the strength of the FRC. Also these crack generates is catastrophic in nature and hence propagates further reducing the life of the FRC material. Hence, this research aims at developing a 3 Dimensional Orthogonal Fabric with Built-in hole in the fabric itself and then making its composites will prevent the drilling of holes, thus strength of the FRC is increased by 30-40% approximately. As the strength of the FRC increases, the thickness of the FRC can be reduced further, hence reduces the weight of the FRC leading to higher pay load possible in aircraft giving higher fuel efficiency.

Keywords: Fiber Reinforced Composite, 3-Dimensional, Orthogonal, NOOBED, Orienting, Crimp.

I. INTRODUCTION

3D composites are creating its acceptance among the composites community, especially the aeronautics, space and defense sectors. Various techniques are available for 3D composites encompassing weaving, stitching, braiding, tufting etc., that are at various stages of development and implementation. Two broad areas of application for 3D composites are in the structural and thermal segments. Opportunities for 3D composites exist in the form of performance enhancements for components having multidirectional stress states, easy & radically different designs, reduced part count and reduced labor cost. The main Challenges that need to be articulated include achieving a balance between in-plane & out-of-plane properties, processing issues for thick & compact 3D structures, out-of-plane testing approaches and integration challenges with metal/2D composites. In many fibre reinforced composites application usually comprises of stacked layers known as 2D laminates, gives better in-plane strength and stiffness properties compared to those of metals and ceramics. Conversely, the application of 2D laminates in some critical structures in aircraft and automobiles has also been restricted by their inferior impact damage resistance and low through thickness mechanical properties when compared against the traditional aerospace and automotive materials such as aluminum alloys and steel. The 2D laminate and 3D woven fabric composite is used in conjunction with some other material when applied in its application area. To join these two or more components the bolts are being used to keep them together and fix them. Now on fitting the bolts on the fabric composite materials requires drilling hole into the composite material. This leads to interruption in the passage of the yarn in 2D laminate or 3D woven fabric and breaks the yarn used in it. Due to this breakage of the yarn composite structure considerably losses its strength and further any mechanical force acts on crack propagation occurs and leading to major damage to the structure.

So there is the need to prevent such damage to the composite material when a hole is created in to the fibre reinforced composite structure.

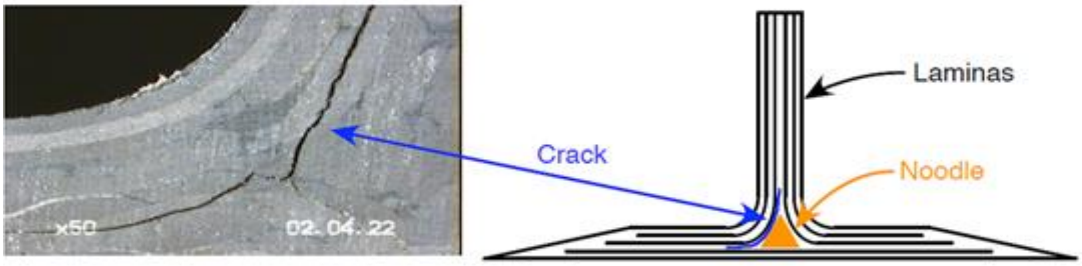

Fig. 1 Crack Propagation in Laminated Composites

II. LITERATURE REVIEW

The 3D fabric are defined as a single fabric system , the consitituent yarns of which are supposedly disposed in a three mutallly perpendicular plane relationship[1]. Khokar defined 3D woven fabrics as a fabric, the constituent yarns of which are supposed to be disposed in a three-mutually-perpendicular-planes relationship[2].

The conventional 2D weaving process (multi-layer weaving) involves the interlacement of the multi-layer warp (Z) and the weft (X) by forming a shed across the fabric-width direction only. Due to limitation of 2D weaving to displace the multi-layer warp yarns in the fabric-thickness direction only. Because of this limitation, the conventional 2D weaving process cannot bring about interlacement of the multi-layer warp (Z), and the vertical set of yarns (Y) which are laid across the fabric thickness direction during the production of non-interlaced 3D fabric.[5,15,18]

Khokar[2] says The process of 'true" 3D weaving may therefore be described as the action of interlacing three orthogonal sets of yarns (multi-layer warp, and the sets of horizontal and vertical wefts).

To overcome the problem of delamination with the existing fibre reinforced composites various attempts were made with plied and stiched fabric for its application which led to the evolution of the newer technique of 3D fabric forming process. This technique was termed as **NOOBING** by Nandan Khokar. Its an acronym for **N**on-interlacing, **O**rthogonally **O**rientating and **Bin**ding[6].

According to Khokar[6] Noobing it can be divided into two distinct types –

a) Uniaxial noobing

b) Multiaxial noobing.

In uniaxial noobing, the resulting 3D fabric thus has the three sets of linear yams (X, Y, Z) in a mutually perpendicular configuration and is a non-interlaced structure as shown in Fig. no.2.(excluding the bindings).

In multiaxial noobing, A set of linear yarns Z, X, ±θ, arrayed in multiaxial orientation in the directions of the fabric's length, width, and two bias angles respectively, is bound using a set of binding yarns Y in the fabric-thickness direction. The yarns Y could be of either single or double type. The corresponding bindings occur above and under the set of Z, X, ± θ yarns and they form two surfaces of the fabric. The resulting 3D fabric has the three sets of linear yarns X, Y and Z in a mutually perpendicular configuration and, additionally, the linear yarns ± θ in bias directions[3,6].

Noobing produces a fabric that comprises crimpless yarns in the directions of the fabric's thickness, length and width. Its structure plays an important role due to its lightweight and strong material and has wide application in aerospace industry [6].

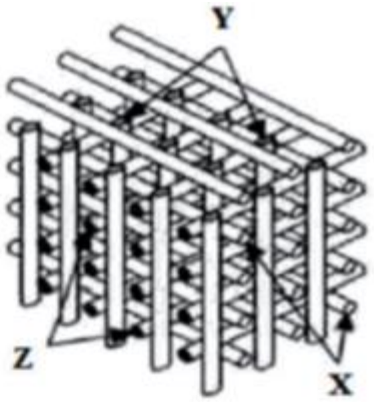

Fig. 2 Uniaxial NOOBED orthogonal structure[3]

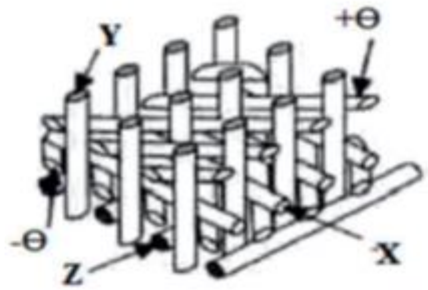

Fig. 3 Multi axial NOOBED orthogonal structure[3]

The amount of Z-yarn and the placement of Z-yarn in the 3D woven preform influence the in-plane properties of the 3D woven structure. When the Z-yarn volume ratio increases, the in-plane properties of the 3D woven structure decrease. The placement of the Z-yarn in unit cell of the 3D woven fabric decreases, failure mode of the 3D woven composite changes and a local delamination occurs.[7,16]

Kadir bilisik[7] tested the Bending strength and modulus of the multiaxis and orthogonal woven composites and found the results as 569 and 715 MPa, and 43.5 and 50.5 GPa, respectively. He noted the Bending strength and modulus of the 3D orthogonal woven composites were higher than those of multiaxis 3D woven composites by about 20% and 14%, respectively. So he concluded that the ±bias yarn orientations on both the surfaces of multiaxis woven composite cause a reduction in bending properties.

Tensile and compression results of multiaxis weave and stitched 2D laminate are comparable. Open hole tensile and compression results of multiaxis woven structure look better compared to that of the stitched 2D laminated structure.[14]

Compression After Impact (CAI) test shows that the 5-axis 3D woven composite is better than that of the stitched 2D laminated structure. Also, damaged area in terms of absorbed energy level is small at the 5-axis 3D woven composite compared to that of the stitched 2D laminated composite.

Bending failure in the multiaxis 3D woven composite where there is a bias yarn breakage at the outside surface of the warp side and a local delamination is seen between the filling and ±bias yarns in places where it is restricted by Z-yarn[7].

In case of inter laminar shear strength of 3D orthogonal woven composite, there is a local yarn breakage between the warp and filling yarns and a local delamination between the warp and filling yarns through-the-thickness direction.[7,13]

Thus in the 3D non-interlaced structure due to presence of Z yarn in orthogonal structure the crack propagation was restricted.[7]

Joining of Composite Material

Mechanical joining is used widely for joining metal/composite components, such as are bolting, riveting, screw, and pin joints. In few cases of joining composite materials where RFI shielding and electrical insulation are required, composite fasteners are used.

Drilling is probably the most frequently used operation in industry. Sometimes, as many as 55,000 holes are generally required to be drilled as in a complete single unit production of the Airbus A350 aircraft.[9] The carbon fibre reinforced plastics (CFRP), owing to their anisotropy and abrasive nature of their carbon fibre content, exhibit totally different drilling results as compared to those of drilling common metals and other materials.[9]

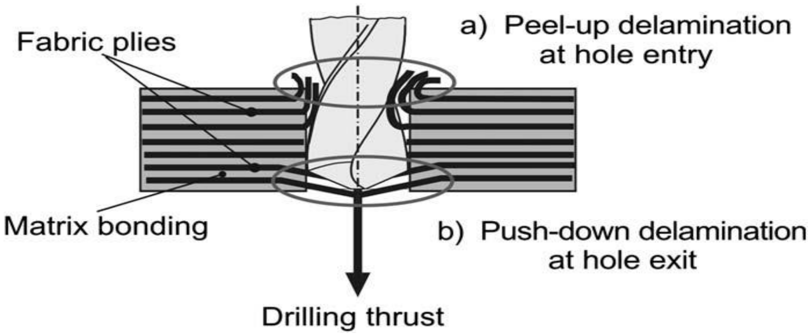

Fig. 4 Classification of delamination.[11]

According to Majumdar[10], drilling creates delamination in laminated composites, as shown in Figures. When the drill bit first enters the laminate, it peels up the uppermost laminae and when it leaves the laminate, it acts as a punch, causing delamination on the other side of the laminate as shown in Fig.4. So to prevent such type of damage to the composite material various type of machining methods[11] are equipped to minimize the damage such as water jet cutting, laser cutting, electrical discharge machining, ultrasonic machining. Various types of drill bits for minimum damage – saw drill, candle stick drill, core drill, step drilling. But using these techniques for machining of the composite will lead to increase in cost of machining for the composite materials.

III. EXPERIMENTAL SETUP

The non-interlaced 3D fabric forming method of producing a 3D woven crimpless fabric is the uncomplicated method with simple fabric construction of 3 sets of yarns incorporated in an orthogonal orientation.

The process of forming the NOOBED fabric is described as -

(a) Assemble essentially three sets of yams linearly (without crimp) in a near orthogonal orientation

(b) Produce only non-interlaced 3D fabric by integrating the employed essentially three sets of yarns through a binding process without interlacing and

(c) Produce a self-supporting, single-fabric system, nonwoven 3D fabric of yams without thermal or adhesive bonding, not plied and stitched fabric system, and comprising yarns/filaments and not short fibres.

To produce a 3D orthogonal fabric with built in holes, a special type of machine/loom is designed to get the desired diameter hole in 3D fabric without interrupting the continuity of the yarn in 2 or more layer fabric. The number of layer of the 3D fabric is decided upon the volume fraction of carbon yarn in the fabric and also on ends per inch and weft per inch and through thickness thread density in the 3D fabric.

These sample fabric will be produced using 6K carbon yarn imported from, Furmosa plastic corporation, Tairylan Division, Taiwan. The TC 35- 6K carbon yarn is used for aviation purpose and it has no. of filaments- 6000 with tensile strength of 410kg/mm2, Yield tex – 400tex, elongation percentage – 1.8% and Density- 1.8gm/cm3

For comparing the strength of the newly developed in built hole 3D fabric, two more type of 3D woven fabric would be manufacture –

1. Laminated plain fabric with drilled hole of desired diameter.

2. 3D orthogonal plain fabric with drilled hole of desired diameter.

These 3 samples produced is then made composite using the infusion method. In this method the fabric sample is laid down in the room temperature and vacuum is created by covering it and resin and hardener is infused in the fabric.

Epoxy Resin ARL135V and Hardener AH422 is used in weighted proportion, 900gm [100%] of epoxy resin and 288gm [32%] hardener is used, kept for 24 hr for complete vacuum infusion. Pre Curing is carried out at room temperature for next 24 hours. Next post curing is done at 5 stages with temperature increase from 80 degree to 180 degree Celsius with 2hrs for each stages of post curing. The fabric is ready to be cut in the desired dimension for mechanical testing CFR composite.

Amongst the 3 samples the laminated CFR composite and 3D orthogonal CFR composite will be drilled hole of desired dimension using the CNC drilling machine.

These sample produced are then tested for its mechanical property. Tensile strength and modulus of the sample gives the stress v/s strain graph of the CFR composite and gives the load value which can be sustained by the CFR composite. The tensile strength of the CFR will be tested on Instron universal tester 500KN tester machine using ASTM D3039.

The fatigue test of CFR gives the accurate measure of the composite when in dynamic state of application. The in plane shear strength /inter laminar shear strength of CFR composite helps in finding the cross plane and in plane strength of the composite and hence analysis the chances of delamination of the CFR composite in case of damage and its propagation.

In next part of the research article the results analysis and its discussion of the various mechanical properties will be presented.

IV. SUMMARY

3D woven fabrics have the potential to reduce aircraft weight by 30%.[12] The composite material is used more than 50% in the aerospace structure. These composite structure are always used in joining with some other material like metal, steel, aluminum or any other. So for joining the components hole is drilled into for fixing them together due to which its damages the fibre present in the fibre reinforced composite material leading to reducing its strength and damaging its structure.

The 3 D woven structure is the Noobed structure as it has crimples yarns present in it and being more advantages than any other 3D woven structure like 3D angle interlock structure, 3D multi-layer stitch structure. The 3D orthogonal structure would have the built hole in it with inserts provided and the continuity of the yarns will not be broken during manufacturing of the special fabric.

Hence to prevent such damage due to drilling hole, my research aims at producing a 3 dimensional orthogonal structure with built in hole present in it which completely eliminates the problem associated with the drilling holes in composites and also regains the strength of composite which was lost due to delamination problem during drilling hole.

I. References

[1]. B K Behera, Rajesh Mishra, 3-Dimensional Weaving, Indian Journal of Fibre and Textile Research, Vol. 33(3), 2008, 274-287.

[2]. Khokar, N. 3D-weaving: theory and practice, Journal of the Textile Institute, Vol. 92(2), 2001, 193-207.

[3]. Gokarneshan, N., and R. Alagirusamy. Weaving of 3D fabrics: A critical appreciation of the developments. Textile Progress, Vol. 41(1), 2009, 1-58.

[4]. Carvelli, V., Gramellini, G., Lomov, S. V., Bogdanovich, A. E., Mungalov, D., & Verpoest, I. Non-Crimp 3D Weave Vs. Laminated Plane Weave Composites: Tension-Tension Fatigue Behaviour. 17th International Conference on Composite Materials (ICCM-17). 2009.

[5]. Khokar, N. 3D Fabric-Forming Processes: Distinguishing Between 2D Weaving, 3D-Weaving and An Unspecified Non-Interlacing Process. Journal of the Textile Institute Vol. 87(1), 1996, 97-106.

[6]. Khokar, N. Noobing: A Nonwoven 3D Fabric-Forming Process Explained. Journal of the Textile Institute, Vol. 93(1), 2002, 52-74.

[7]. Bilisik, Kadir. Multiaxis three-dimensional weaving for composites: a review. Textile Research Journal, Vol 82(7), 2012, 725-743.

[8]. Stig, Fredrik, and Stefan Hallström. Assessment of the mechanical properties of a new 3D woven fibre composite material. Composites Science and Technology, Vol. 69(11-12) 2009, 1686-1692.

[9]. Faraz, Ali, Dirk Biermann, and Klaus Weinert. Cutting edge rounding: An innovative tool wear criterion in drilling CFRP composite laminates. International Journal of Machine Tools and Manufacture, Vol. 49(15), 2009, 1185-1196.

[10]. Mazumdar, Sanjay. Composites Manufacturing- Materials, Product and Process Engineering. London : CRC Press, 2001.

[11]. Hocheng, H., and C. C. Tsao. The path towards delamination-free drilling of composite materials. Journal of materials processing technology, Vol. 167 (2-3), 2005, 251-264.

[12]. Hearle, J. W. S., and X. Chen. 3D woven preforms and properties for textile composites. Seventeenth International Conference on Composite Materials, Edinburgh. 2009.
[13]. Nagai, Kanehiro, Nagai, K., Yokoyama, A., Maekawa, Z. I., & Hamada, H. Strength analysis for three-dimensional fiber reinforced composites. Advanced Performance Materials Vol.2(2), 1995, 161-176.
[14]. Behera, B. K., and B. P. Dash. An experimental investigation into the mechanical behaviour of 3D woven fabrics for structural composites. Fibers and Polymers, Vol.15(9), 2014, 1950-1955.
[15]. Khokar, Nandan. Woven 3D fabric material. U.S. Patent No. 6,338,367. 15 Jan. 2002.
[16]. Hallström, Stefan. 3D-Textile Reinforcement In Composites–Mechanics, Modelling, Pros And Cons. 15th European Conference on Composite Materials: Composites at Venice, ECCM 2012, 24 June 2012 through 28 June 2012, Venice, Italy. European Conference on Composite Materials, ECCM, 2012.
[17]. Sanjay K. Parmar, Shweta J. Doctor 3-Dimensional Solid Woven Architectures And Manufacturing. The Journal of Textile Association, Vol. 73(1), 2013, 636.
[18]. Sugun, B. S., and Ramesh Sundaram. 3D composites: opportunities & challenges. Journal of the Indian Institute of Science 95.3 (2015): 221-232.
[19]. P.P.Kolte, V.S.Shivankar, A.L.Gulve, Sagar Chore, 3D Fabric - A result of new weaving Technology, Asian Textile Journal, Aug. 2011, 78.