

An Overview on 3D Composites – its Definition, Fabrication & Applications

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Abstract--- *Fibre-reinforced composites have excellent mechanical properties, such as high specific strength, high specific stiffness etc. In particular, laminated composite structures have extensively been used where the in-plane properties are important. However, laminated composites have relatively poor mechanical properties in the thickness direction and are prone to interlaminar delamination. In an attempt to overcoming this difficulty, three-dimensional (3D) braided composites have been developing in the past two decades. These materials have better out-of-plane stiffness, strength and impact resistance, reduced fabrication cost, increased through-thickness mechanical properties and therefore have potential applications in the aerospace, automobile and marine industries. As the application of 3D braided composites is becoming wider, a lot of models have been developed to analyse its mechanical properties. Due to the complicated architecture, these analyses are very challenging. To this end, in this paper an attempt has been made to collect literature survey on definition, manufacturing methods & applications of 3d composites.*

Keywords--- *3D Composites, Stiffness, Strength, Light Weight*

I. INTRODUCTION

Composites have emerged as important materials because of their light-weight, high specific stiffness, high specific strength, excellent fatigue resistance and outstanding corrosion resistance compared to most common metallic alloys, such as steel and aluminium alloys. Other advantages of composites include the ability to fabricate directional mechanical properties, low thermal expansion properties and high dimensional stability. It is the combination of outstanding physical, thermal and mechanical properties that makes composites attractive to use in place of metals in many applications, particularly when weight-saving is critical.^[1-3]

Fibre reinforced polymer (FRP) composites are used in almost every type of advanced Engineering structure, with their usage ranging from aircraft, helicopters and spacecraft through to boats, ships and offshore platforms and to automobiles, sports goods, Chemical processing equipment and civil infrastructure such as bridges and buildings. The usage of FRP composites continues to grow at an impressive rate as these materials are used more in their existing markets and become established in relatively new markets such as biomedical devices and civil structures. A key factor driving the increased applications of composites over recent years is the development of new advanced forms of FRP materials. This includes developments in high performance resin systems and new styles of reinforcement, such as carbon nanotubes and nanoparticles. A major driving force has been the development of advanced FRP composites reinforced with a three-dimensional (3D) fibre structure. 3D composites were originally developed in the early 1970s, but it has only been in the last 10- 15 years that major strides have been made to develop these materials to a commercial level where they can be used in both traditional and emerging markets.

Since the late-1960s, various types of composite materials with three-dimensional (3D) fibre structures (incorporating z-direction fibres) have been developed to overcome the shortcomings of 2D laminates. That is, the development of 3D composites has been driven by the needs to reduce fabrication cost, increase through-thickness

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mechanical properties and improve impact damage tolerance. The development of 3D composites has been undertaken largely by the aerospace industry due to increasing demands on FRP materials in load-bearing structures to aircraft, helicopters and space-craft. The marine, construction and automotive industries have supported the developments. 3D composites are made using the textile processing techniques of weaving, knitting, braiding and stitching. 3D composites are also made using a novel process known as z-pinning.

II. WEAVING

Weaving is a process that has been used for over 50 years to produce single layer, broad cloth fabric for use as fibre reinforcement to composites. 2D woven fabric has two yarn sets as warp (0°) and filling (90°) and interlaced to each other to form the surface. It has basically plain, twill and satin weaves which are produced by traditional weaving. But, 2D woven fabric in rigid form suffers from its poor impact resistance because of crimp, low delamination strength because of the lack of binder fibres (Z-fibres) to the thickness direction and low in-plane shear properties because no off-axis fiber orientation other than material principal direction.^[4] Although through-the-thickness reinforcement eliminates the delamination weakness, this reduces the in-plane properties (Dow and Dexter, 1997, Kamiya et al., 2000). On the other hand, uniweave structure was developed. This same technique has been modified to produce 3D woven materials that contain through-thickness fibres binding together in plane fabrics. A variety of 3D woven composites have been manufactured using modified weaving looms with different amounts of x, y and z direction fibres so that properties can be tailored to a specific application.

III. 3D ORTHOGONAL FABRIC

3D orthogonal woven preforms have three yarn sets: warp, filling, and z-yarns (Bilisik, 2010).^[5] These sets of yarns are all interlaced to form the structure wherein warp yarns were longitudinal and the others were orthogonal. Filling yarns are inserted between the warp layers and double picks were formed. The z-yarns are used for binding the other yarn sets to provide the structural integrity. The unit cell of the structure is given in Figure 1.

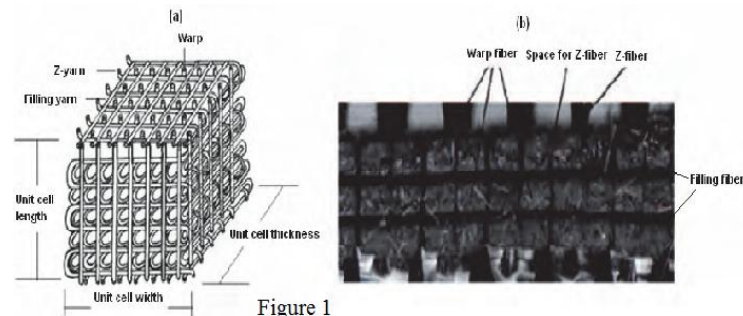
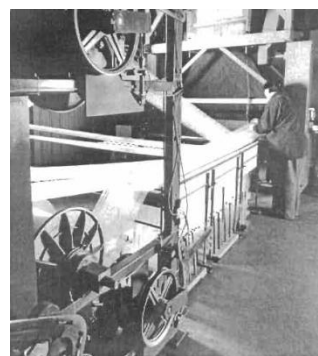


Figure 1



Multilayer weaving loom (courtesy of the Cooperative Research Centre for Advanced Composite Structures, Ltd)

Figure 2

The first major difference between conventional weaving and multilayer weaving is the requirement to have multiple layers of warp yarns. The greater the number of layers required (and thus the thickness of the preform) or the wider the fabric produced, means a larger number of individual warp yarns that have to be fed into the loom and controlled during the lifting sequence. Therefore the source of the warp yarn for multilayer weaving is generally from large creels in which each warp yarn comes from its own individual yarn package. Multiple warp beam

systems have also been used although this is not as common.. Most multilayer weaving is therefore currently used to produce relatively narrow width products, where the number of warp ends is relatively small, or high value products where the cost of the preform production is acceptable.

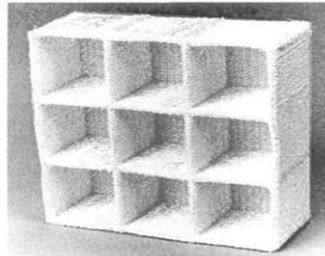
Asmost 3D composites are produced from high performance yarns (carbon, glass,ceramic, etc) standard textile tensioning rollers are unsuitable and tension control on the individual yarns during the weaving is critical in obtaining a consistent preform quality. This is generally accomplished through spring-loaded or frictional tension devices on the creel or through hanging small weights on the yarns before entering the lifting device. Figure 2 illustrates the use of multiple warp beams and hanging weights in multilayer weaving. The lifting mechanisms are the same as used in conventional weaving although the heddle eyes through which the yarn passes tend to be smoothed and rounded to minimisefriction with the more brittle high performance fibres. Jacquard lifting mechanisms tend to be used more frequently as their greater controlover individual warp yarns offers more flexibility in the weave patterns produced. The weft insertion is accomplished with standard technology (generally a rapier mechanism) inserting individual wefts between the selected warp layers. Variations in the lifting andweft insertion mechanisms to allow multiple sheds to be formed and thus multiplesimultaneous weft insertions have also been developed and would allow a fasterpreform production rate. This type of technology is often regarded as the true 3Dweaving.

3.1. Application of Weaving

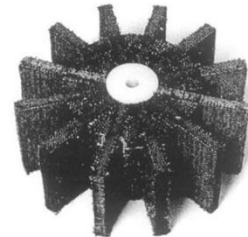
- Turbine engine thrust reversers, rotors, rotor blades, insulation structural reinforcement and heat exchangers
- Engine mounts
- Nose cones and nozzle for rockets
- T-section elements for aircraft frame structures
- Rib, cross-blade and multi blade stiffened aircraft panels
- Leading edges and connectors to aircraft wings
- I-beam for civil infrastructure
- Manhole covers



(a)



(b)



(c)

Examples of 3D Woven Preforms.(a)Cylinder and Flange (b)Egg Create Structures (c)Turbine Rotors Woven by Techniwave(Photographs Courtesy of Techniweave Inc.)

3.2. Advantages in using for some Specific Application

H-shaped connectors on the beech starship: 3D composite used for joining the honey comb wing panels together. It reduces the cost of manufacturing of wings as well as improves the stress transfer and reduces the peeling stress at the joints.

Construction of stiffeners for the air inlet duct panel to the joint Strike Fighter (JSF) Lockheed Martin: 3D woven composites are being used in the stiffeners for the air inlet duct panels .The use of 3D woven stiffeners eliminates 95% of the fasteners through the duct, thereby improving the aerodynamic and signature performance, eliminating fuel leak paths, and simplifying the manufacturing assembly compared with conventional 2D laminate o aluminium alloy. Ducts can be produced in half the time and two-thirds of the cost of current inlet ducts and save 36 kg in weight and at least US\$200,000 for each duct. 3D woven composite in rocket nose cones:It provides high temperature properties, delamination and erosion resistance compared with traditional 2D laminates. It is estimated that 3D woven nose cones at about 15%of the cost of the conventional cones, resulting in significant cost saving.

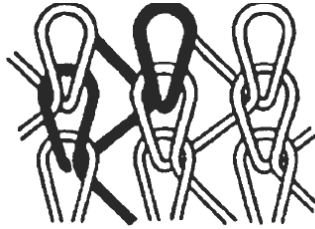
IV. 3D KNITTED COMPOSITE

4.1 Knitting Process

Knitting of composites can be done by traditional methods like warp and weft knitting. Both techniques performed on standard industrial knitting machines with performance yarn such as glass and carbon.

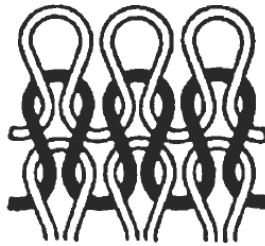
4.2 Warp Knitting

Here multiple yarns are fed in the direction of fabric production and each yarn form a line of knit loops in fabric direction. Here, there is individual supply of yarn feeding each knitting needle.



4.3 Weft Knitting

Here single feed of yarn coming to the machine at 90° of the fabric Warp knitted fabric architecture production. This yarn forms a row of knit loops across the width of the fabric. Here yarn carrier moves across width of needle bed (or around circumference for circular machine) draws the yarn into the needle for knitting.



Weft Knitted Fabric Architecture

Weft knitted fabric architecture Formation of knitted fabric is accomplished through a row of closely spaced needles (needle bed) which pulls loops of yarn through previously formed knit loops. The needle bed are circular or in flat configuration. Increase in needle bed in machine increases complexity of fabric knit architecture.

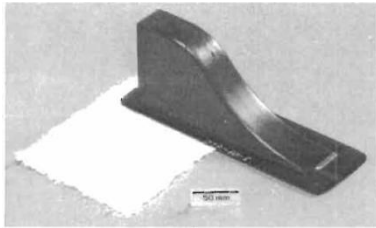
Another 3D knitted fabric manufactured by verpoestetal known as sandwich process. It is produced by simultaneously knitting top and bottom skin on a double bed wrap knitting machine. As two fabrics are being formed, yarns are swapped between two faces to create the connecting pile yarns, thus binding the two faces into integral sandwich fabric. Here the density if the pile yarn can be varied and their orientation can be aligned vertically or at an angle to face warp direction.

Advantages:

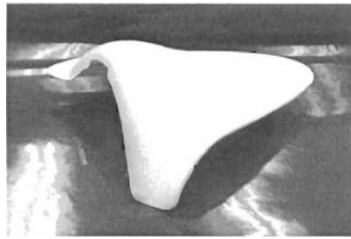
- In knitted fabric there is high degree of yarn curvature as a result ideally used to manufacture non-structural components of complex shape
- Reduced amount of material wastage because fabric can be stretched to cover the complete surface without the need to cut and overlap section.
- 3-D knitted sandwich products have high peel and delamination resistance By changing the knit architecture properties of the fabric can be varied.

Application:

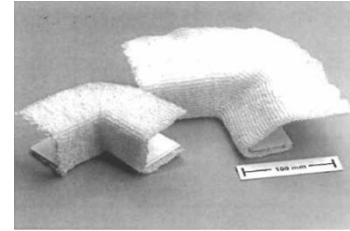
- Aircraft structures like wing stringers, wing panels, jet engine vanes, T-shape connectors, I-beams.
- Manufacture of the bulkhead to the new airbus A-380.
- In non-aerospace like bumper bars, floor panels & door member for automobiles, rubber tip fairings, medical prosthesis and bicycle helmet.



Composite window frame



Helicopter door track pocket



Aircraft push rod fairing

V. BRAIDING

Braiding is the technique in which the counter rotation of interlinked yarn carriers forms a braided fabric. This movement of yarn carriers is accomplished by horn gears. The fabric architecture produced by this process is highly interlinked and normally in flat or tubular form as shown in figure 3. The shape and size of the braided fabric depends on number of yarns, their size and required braid angle. The braiding process can also be used to produce quite intricate shape with the help of mandrels. The primary difficulty with traditional braiding technique is that it cannot make thick walled structures. Even if it made, we can't achieve through thickness strength. In order to manufacture such a structure 3-D braiding technique is developed.

5.1 3D Braiding

3-D braiding technique was first developed by general electric in 1971 and further developed and patented by Florentine in 1982.

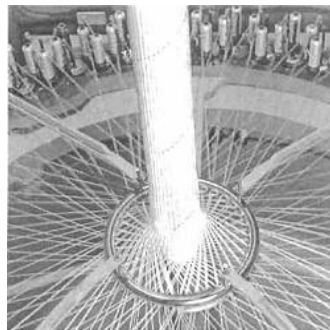


Figure 3

5.2 Four step 3-D Braiding

4-step process utilizes a flatbed containing rows and columns of yarn carriers that form the required shape of the preform. There are 4 separate sequence of row and column motion which act to interlock the yarns and to produce the braided preform.

5.3 Four step 3-D Braiding

It includes a large number of yarns fixed in the axial direction and smaller number of braiding yarns. The arrangement of the axial carriers defines the shape of the preform to be braided and the braiding carriers distributed around the perimeter of the axial carriers move completely through the structure between the axial carriers. This is relatively simple sequence motion capable of producing any intricate shape.

5.4 Multilayer Interlock Braiding

This method is more similar to 2-D braiding in its operation. The machinery has number of standard circular braiders being joined to form a cylindrical braiding frame. This frame has a number of parallel braiding tracks around the circumference of the cylinder. But the mechanism allows the transfer of yarn carriers between the adjacent carriers thus forming a multilayer fabric.

Advantages

Some of the major advantages of 3-D braiding are-

- It is possible to braid inserts or holes into the structure which have greater degree of stability compared to machined holes.
- Braided pattern can be varied during the operation so that change in cross section shape is possible. We can even produce tapered shape, thick walled tubular shape, 90⁰ bend shape. It has more torsional stability, durability and structural integrity.

Application

Aerospace Applications

- It is used in manufacturing airframe spars, F-section fuselage frames, fuselage barrels, tail shafts, rib stiffened panels, rocket nose cone, rocket engine nozzles.
- Other applications:
- In manufacturing Connecting rods, bifurcated beams ship propeller blade, I, C, J, T sections, biomedical devices and heart bypass for use in vascular surgery.

VI. Z PINNING

Z pinning consists of embedding previously cured reinforcement fibres into thermoplastic foam that is then placed on top of a prepreg, or dry fabric, lay-up and vacuum bagged. Through judicious choice of the material, the foam will collapse as the temperature and pressures are increased, allowing the fibres to be slowly pushed into the lay-up (see Figure 3). This method can be used during the normal autoclave cure of prepreg and for both prepreg and dry fabric can be performed whilst the lay-up is on the tool surface itself, thus saving extra steps in the manufacturing process. A version of this technology can be used at room temperatures as it utilises an ultrasonic horn that heats up a local area of the z-pin foam and preform, thus allowing a plunger to push the pre-cured reinforcement yarn into the lay-up. Both methods have been successfully applied to carbon epoxy composites with silicon carbide, boron and carbon reinforcement yarns.

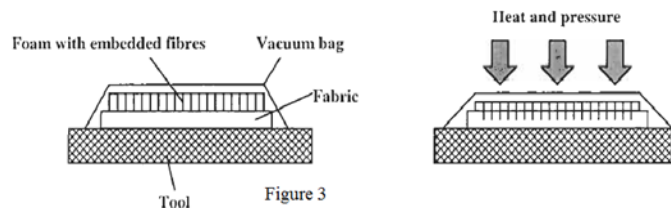


Figure 4

VII. CONCLUSIONS

In this work, a detailed literature review on 3D composites which provides insight on its definition, fabrication and applications have been provided. This information may provide the researchers, designers in general and composites community in particular a clear understanding of 3D composites for a particular application.

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