A REVIEW OF FABRICATION METHODS AND STACKING SEQUENCE ARRANGEMENTS OF FIBER FOR COMPOSITE MATERIAL

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Abstract

In the recent trends, the demand for composite material is growing high due to its advantages in today's world. The present study provides an outline of different fabrication methods of the composites such as hand lay-up, VARTM, pultrusion, filament winding, and compression moulding process etc., It also provides an overview of stacking sequence of the fiber reinforced composites. The paper signifies outcome as stacking sequence is a significant parameter to improve the mechanical properties; Stacking sequence gives better bonding and strength to the composites; VARTM process is better compared to other fabrication methods and preferred for fabrication of high fiber volume fraction of composites; Hand lay-up technique is easy and cheap technique to fabricate the composites, mostly preferred in fabrication of composites.

Index Terms: Composite Material, Fabrication Methods, Mechanical properties, Stacking Sequence.

I. INTRODUCTION

Composites manufactured products are being used in almost every type of applications in our day to day life and their use keeps on developing at an amazing rate. Mechanical properties of composites are controlled by elements such as nature of matrix, fiber inter phase matrix, volume of the fiber, aspect ratio of the fiber, fiber orientation etc. [1]. Stacking sequence of the fiber had a major role in the improvement of mechanical property [4]. The principle motivation behind the hybridization is to set up another material that will hold the benefits of its constituents however not their drawbacks. Along these lines, crossbreed structures empower Architect to plan different materials with customized properties for particular applications that can't be accomplished in two-fold frameworks [7]. The impact of fiber content on the properties of fiber strengthened composites is especially important. The increment in fiber amount prompts an expansion in elastic properties. The stacking arrangement has a noteworthy part of a change in a mechanical property of composites [8].The real advantage of composite parts is quality/weight proportion, which is perfect for aviation application.

II. LITERATURE REVIEW

Different fabrication methods of composites, in general, can be divided into two types namely (a) open mould process (b) close mould process. Open mould process is the most adaptable of all composite creation forms as part size and plan alternatives are for all intents and purposes limitless. For open mould fabrication method, the top layer of the reinforcement and matrix are presented to the climate, bringing about the unrestrained surface condition. Subsequently, the tooling manufacture process is generally simple and minimal effort, quick item advancement series is conceivable to be actualized utilizing this technique [9]. This review will discuss three main processes of fabrication of composites. Close mould procedures, for example, Light Resin Transfer Molding, Reusable Bag Molding and Vacuum Infusion Process are utilized to create exactness parts at bringing down expenses for a range of utilizations. This procedure is commonly automatic and requires superior instruments and it can produce bulk parts and in high volume. In this review closed mould process, vacuum infusion process, compression moulding, resin transfer moulding, pultrusion, and vacuum bag moulding were discussed. Selection of fabrication methods depends on many parameters such as resin system, material, parts size. Various fabrication methods explain in below chart.

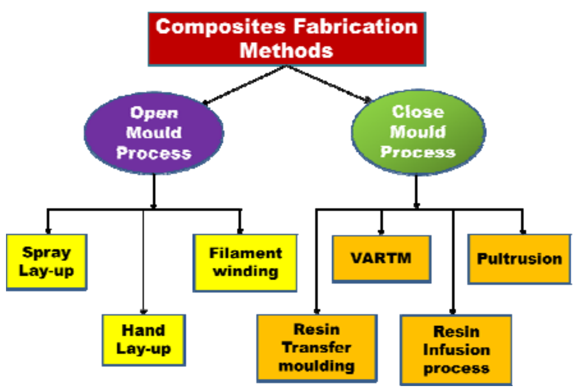

Fig. 1: Fabrication method of composites

The process of fabrication according to volume production shown in below table I.

Table I: Fabrication method according to volume production

Sr. No.	Low volume	Medium volume	High volume
1	Spray lay-up	Centrifugal casting	Continuous lamination
2	Vacuum infusion process	Wet lay-up compression moulding process	Reinforced reaction injection moulding
3	Hand lay-up	Filament winding	Compression moulding
4	Vacuum Bagging	Resin transfer moulding	Pultrusion

A. Fabrication methods of composites

1. Hand lay-up process

M. Santhosh Kumar (2015) used hand lay-up fabrication method for different fiber orientation of the composites [11]. Hand lay-up is the most favorable process for the fabrication of composite. This process is widely used to the lower installed cost as compared to the resin transfer moulding process. The use of the matrix and reinforcement material is a determining factor for curing time. 24 hours curing time is required for the fabrication of composites. Various aircraft and automotive parts can be fabricated by hand lay-up process including car dashboard, cabin parts of the interior. Hand lay-up process is shown below in fig. 2 [12] - [14].

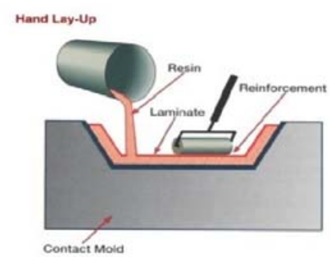

Fig. 2: Hand lay-up process set-up

2. Spray lay-up process

In the spray lay-up technique compressed air supply to the gun is used to resin and fiber (chopped) spray on the mould. A chopped form of fiber is used as reinforcement material in this process. To eliminate the air between the films roller is applied to the sprayed materials. After curing, calcium carbonate and aluminum trihydrate fillers are added using a high shear mixing unit. The curing depends on the resin and room temperature. Hence this process is more suitable for medium load carrying parts such as boats and trucks fairing. It is a very efficient process for construction small to large parts. It utilizes lower cost tooling as well as lower cost of systems.

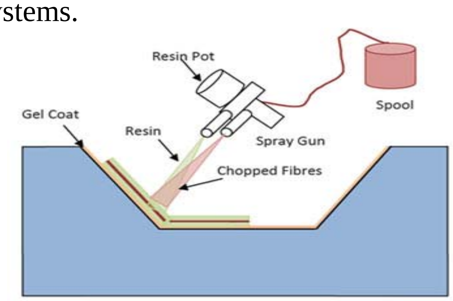

Fig. 3: spray lay-up process

Kikuchi (2013) reported on mechanical properties of jute composite by spray lay-up revealed a huge variety of rigidity notwithstanding stable versatile modulus esteems. It was depicted that the nature of items is relative to the administrator's aptitude. There are a few components influencing the result of shower up the process [15] Liakus (2009) **(**explored microstructure-property predictions for short fiber reinforced composite assemblies in the opinion of a spray lay-up process. In the examination, varieties in fiber length, and in addition to spray lay-up disposition designs have been distinguished as two central points adding to the mechanical quality of the composite products created [16].

3. Filament winding

Filament winding is a nonstop design strategy that can be very computerized and repeatable, with generally low material expenses. Along, barrel-shaped device called a mandrel is suspended on a level plane between end bolsters, while the "head" the fiber application instrument moves forward and backward along the length of a pivoting mandrel, putting fiber onto the device in a foreordained arrangement. PC controlled fiber winding machines are accessible, outfitted with from 2 to 12 tomahawks of movement.

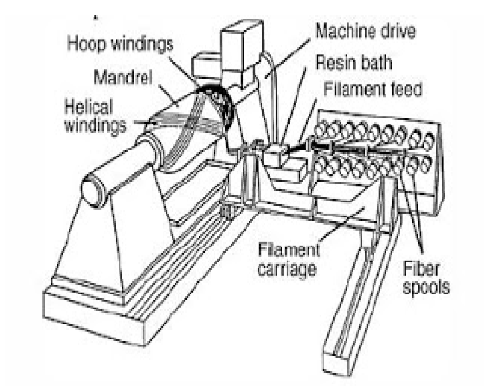

Fig. 4: Filament winding

Ductile materials are generally utilized as the liners, for example, delicate aluminum, with just negligible load-sharing capacities. The fiber is for the most part connected as lace of different drags wetted in resin shower. Madhavi (2014) outline and examination of fiber twisted COPV with coordinated end vaults, material description of FRP of carbon T300/Epoxy for different setups are resolved to utilize fiber rolling system. It is discovered that having interchange circle and helical layers with loop layers as the best and base most layers, gave the burst estimation of 12.4 MPa in the round and hollow zone [21]. Cherniaev (2016) shows both experimental and geometric study of hypervelocity impact (HVI) damage by orbital fragments in the composite materials fabricated by filament winding. The result showed that the filament winding pattern with a higher degree of the interweaving of filament bands demonstrated better ability to hinder the dissemination of HVI encouraged damage, even in the presence of pre-loading [22].

4. Resin film infusion

Resin film infusion method is a crossover procedure in which a dehydrated preform is set in a form over a layer, or incorporated with different layers, of the high-thickness resin film. Under connected warmth, vacuum and weight, the resin condenses and is drawn into the preform, bringing about uniform gum appropriation, even with high-thickness, hardened resin, on account of the short stream remove.

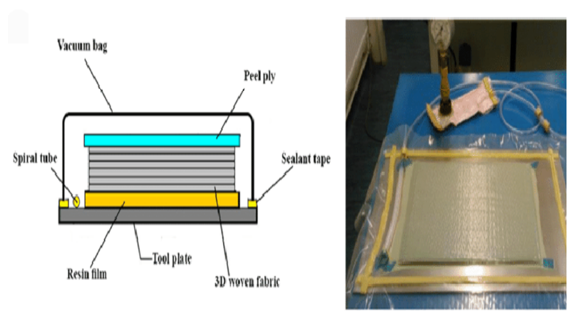

Fig. 5: Resin film infusion

The previous study on this method done by Kim (2015**)** on hybrid glass fiber reinforced plastic (GFRP) and shows that the vacuum infusion process gives higher ultimate strength, modulus, shear strength, and displacement over thickness value than the hand layup samples in both tension and compression tests [19].

5. Pultrusion

Pultrusion has been utilized for quite a long time with glass fiber and polyester gums, however, over the most recent 10 years, the procedure also has discovered application in cutting edge composites applications. In the thermoplastic pultrusion method embellishment, resin and reinforcement filaments are pulled through warmth kick the bucket. As the warmth and weight created, pitch begins to dissolve and impregnate into the support fiber. There are a few parameters, for example, preheating strategy, bite the dust temperature and pulling speed that speaks to deciding variables in regards to a potential mechanical application. Tube rolling is a longstanding composites fabricating process that can create limited length tubes and bars.

Memon (2014) reported on the mechanical properties of jute fiber reinforced composite using pultrusion moulding. The experimental results show that the design of the middle of the road material and the trim temperature impacted the mechanical properties of the part delivered. It was noticed that the impregnation quality expanded with the extent of trim and expanding temperature decreased the mechanical properties because of the disintegration of jute fiber [25].

5. Vacuum Assisted Resin Transfer Moulding (VARTM)

M. R. Hossain (2013) was used the vacuum assisted resin infiltration technique in their experiment. VARTM is a closed mould, out of autoclave composite manufacturing process. VARTM is different than resin transfer moulding with its unique characteristic being the replacement of the top portion of a mould tool with a vacuum bag and the use of a vacuum to help in resin flow. The method comprises the use of a vacuum to enable resin flow into a fiber layup organized within a mould tool covered by a vacuum bag. After the impregnation happens the composite part is permissible to cure at room temperature with an optional post cure sometimes carried out. Hence from the literature conclude that VARI is a fine-accepted technique [3].

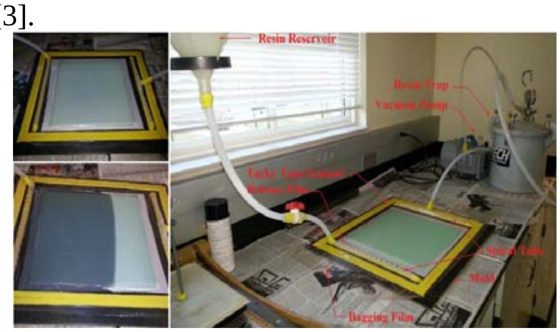

Fig. 6: VARTM set-up

There were many composites fabricated by using VARTM process. Liu (2014) utilized VARTM set-up for the creation of the composites and announced that ductile disappointment was begun from delamination edge at round edge progress zone of the T joints at also the end of the associating pole and the disappointment quality was dictated by interlaminar quality [19].

K. Senthilkumar (2016) was used compression moulding process for fabrication of composites. In the process, fibers were fixed and assemble carefully as long fiber in the mould according to the type of selected orientation of the fiber. The specific angle of fiber orientation and mold consisted of marking at every angle. Resin and catalyst used for the accelerator. Over the fiber, the mixture was pour and kept in molding machine at 17 MPa and manufactured composite got after 24 hours. [2] Hamill (2012) examined the surface porosity factors amid vacuum packing technique and recognized a few parameters that influence air clearing including cooler and out time, vacuum hold time, material and process changes.

Effect of stacking sequence of the fiber on mechanical property of composites

Stacking sequence has a major role in the improvement of mechanical property of composites. Simple fiber oriented composite.

M. R. Hossain (2013) investigated the effect of orientation of fiber on mechanical properties of sisal fiber reinforced epoxy composites. Following stacking sequence was used. It is 0°/0°/0°/0°, 0°/+45°/-45°/0° and 0°/90°/90°/0°. In the case of 0°/0°/0°/0° and 0°/+45°/-45°/0° lamina composites, longitudinal tensile strength has been found to be higher than that of the transverse direction [3].

C. H. Naresh (2016) reported on the effect of stacking sequence on mechanical property of hybrid composites (synthetic and natural fibers). Glass/hemp/jute/epoxy laminates were fabricate using different stacking sequence and orientation by hand lay-up method. And stacking sequence was glass/hemp/jute, hemp/jute/glass, jute/glass/hemp. The fiber was arranged in horizontal and unidirectional. Hence from the experiment horizontal (jute fiber) has a major strength compared to other stacking of composites [26].

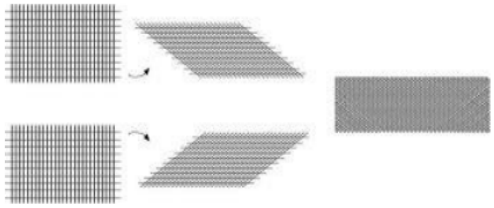

Fig. 7: Fiber stitch

The non-crimp fabric also called as multi-axial fabric, consists of more layers contained sufficiently of parallel fibers, which is locked in place by a secondary non-structural stitching matrix. Weave & Stitch and Concurrent Stitch are two common production types of this fabric [26]. Hence, from the experiment found that the non-crimp fabrics can be configured according to any unique structural requirement at any angle, beyond the simple 0/90° of woven fabrics during the manufacturing process to obtain superior mechanical properties of final composite components. The fibers are always keeping straight without crimping due to the preparation of layers, that means higher tensile strength, compression and modulus can be achieved in the final composite components [57].

S. A. Hitchen (1996) reported that by optimizing the stacking sequence the hybrid composites showed a mechanical performance equal to that of the ultra-high-performance material and a performance superior to the standard material. The following stacking sequences were investigated: Sisal, [(45,0,)&; SS2, [(45)2,041,; ss3: [(+45,0,-45,0),1,; ss4, [(0,+45,0,-45)]. Hence from the experiment similar result was found by optimizing the stacking sequence and distributing the 0" plies through the laminate thickness [9].

K Senthilkumar (2016) reported that the outer layers of fibers oriented in 0° at both ends of composites.0°/90°/0°,0°/45°/0°,0°/90°/45°/45°/90°/0 and 0°/45°/90°/90°/45°/0° showed higher tensile strength than the other kind of composites. Hence the fibers situated at 0º along the applying load conditions would withstand higher load while testing [2]. Kumaresan (2015) studied the effect of sisal fiber orientation on tensile and flexural strength. Orientation used in this research work was 0/ 90°, 90°, 45°.In this research work, they had taken 3 trials of specimens for testing of tensile strength. Among these, the 90° [Uni-directional] orientation shows maximum strength. It was 38.83 MPa and higher than 0/ 90°, 45° [1]. Manjeet Singh (2015) reported on the effect of ply orientation on strength and failure mode of pin-jointed unidirectional laminates. Glass-epoxy composite laminates were prepared with [0°/45°/90°], [0°/45°/0°] and [0°/90°/0°] ply orientations. Hence from the experiment they conclude that ply orientation of [0°/45°/0°] shows higher mechanical properties in the longitudinal direction but in [0°/90°/0°], orientation shows high tensile properties in the transverse direction. Experimental results concluded that the bearing strength of [0°/90°/0°] ply orientation was 10-12% higher than [0°/45°/0°] ply orientation [22].

Chavan (2016) reported on the fabrication of glass/epoxy composite material. In the study, they had prepared the composite in different stacking sequence. And stacking sequence was [0° / 90° / 0° / 90°], [0° / 30° / 60° / 90°] and [0° / +45° / 90° / -45°] prepared with different weight ratio of fiber by hand lay-up method. Hence from the study observed that the effects of the fiber orientation 0°/ 90°/0°/90° with fiber show better tensile strength and flexural strength when compared to another stacking sequence of the glass fiber composites and specific strength and stiffness are found highest in longitudinal direction[23].

The outcome of the stacking sequence is shown in table II. Table II also shows the better stacking sequence for the improvement of the mechanical properties.

Table II: Different stacking sequence of the fiber

Sr.No	Material	Stacking sequences of composites	Best (for mechanical properties)	Reference No.
1	Sisal	0°/90°, 90°, ±45°	90°	[1]
2	Sisal	90°/0 ° /90 °, 0 ° /90 ° /0 °, 90 ° /0 ° /0 ° /90 °, 0 ° /45 ° /0 °,	0 ° /90 ° /0 °	[2]

		0 ° /90 ° /45°/45°/90°/0°, 0°/45°/90°/90°/ 45°/0°.		
3	Glass	30°, 45°, 90°	90°	[8]
4	Glass	0°, 30°, 45°, 60°, 90°	0°	[23]
5	Glass	0°/90°/0°/90°, 0°/30°/60°/90°, 0°/45°/90°/45°	0/90/0/90	[12]
6	Carbon	±30°, ±45°, ±90°	±90°	[14]
7	Kevlar/glass	0°/90°, 45°/45°/, 30°/60°	0/90	[6]
8	Jute	0°/0°/0°/0°, 0°/±45°/±45°/ 0°, 0°/90°/90°/0°	0°/0°/0°/0°	[3]
9	glass	0°/45°/90°, 0/45°/0°, 0°/90°/0°	0°/45°/0°	[22]

III. SUMMARY

The purpose of present work is to highlight the fabrication methods of composite and effect of stacking sequence of the mechanical property of the composites. Fabrication methods, stacking sequence and fiber orientation play an essential role in the improvement of the mechanical property of the composites. In this paper generally used composite fabrication methods were discussed. From the discussion shows that VARTM is a most effective method for the fabrication of the composite because of high fiber volume, low void content, good environmental control as compared to another fabrication process. But here hand lay-up has mostly used the technique for the fabrication of composites because hand lay is a low cost consumable, less requires skilled operators and high fiber volume. So from the literature survey, most researchers preferred hand lay-up method for the fabrication of composites. In this paper stacking sequence of the fiber also discussed. From the literature shows that Stacking sequence starts from 0° fiber orientation better tensile strength gives as compared to 90°/0°/90°, 45°/0°/0°/45°, 60°/45°/45°/60° etc. Fiber material also depends on the improvement of the mechanical property. For example, Glass/hemp/jute/glass (G/H/J/G) stacking sequence gives better mechanical property as compared to hemp/glass/jute/hemp stacking sequence.

IV. CONCLUSION

The present study concludes following outcomes.

1. Different fabrication methods used for the fabrication of the composite but VARTM is a good as compared to other fabrication process but hand lay-up is a generally used technique because hand lay-up is a low investment cost, less requirement of a highly skilled operator.
2. Stacking sequence also an effective parameter to the improvement of mechanical property because Stacking sequence gives better bonding and strength to the fiber. In the stacking sequence fiber material also depends on the improvement of the mechanical property.
3. Layer by layer proper selection of fiber (reinforcement material) in the fabrication of composites gives better mechanical property. From the literature shows that Stacking sequence starts from 0° fiber orientation better tensile strength gives as compared to another stacking sequence of fiber.

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