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Effect of Non-Crimp Fabric Structure on Mechanical Properties of Laminates

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Abstract**—**The textile preforms play a key role in providing the mechanical properties and gives the idea about selection parameter of preforms to improve the quality and performance of laminates. The main objectives of this work are to study the effect of non-crimp fabric preform structure in final properties of laminates. It has been observed that the multi-axial preform give better mechanical properties of laminates as compared to woven and biaxial fabrics. This study investigated the effect of different non-crimp glass preform structure on tensile strength, bending and compression properties of glass laminates. The different woven, bi-axial and multi-axial fabrics with similar GSM used to manufacture the laminates using polyester resin. The structural and mechanical properties of preform and laminates were studied using standard methods. It has been observed that the glass fabric geometry, including type of weaves, warps and filling density and number of layer plays significant role in deciding mechanical properties of laminates.

Keywords**—**Preform, non-crimp, laminates, bi-axial, multiaxial.

I. Introduction

THE technical textile has globally established its market in a very few decades, extending its wings almost in every sectors of technology. One of the technologies is the textile composite manufacturing. The textile preforms play a key role in providing the mechanical properties and gives the idea about selection parameter of preforms to improve the quality and performance of laminates. It has been observed during study that the multi-axial preform give better mechanical properties of laminates compare to woven and biaxial fabrics.

The textile fabrics are generally having crimp structures, which deteriorate the mechanical properties of the textile composite. Hence conventional techniques are modified to develop non-crimp fabric for textile composites. New techniques are developed to produce non-crimp and multi-axial structures. The properties of laminates are greatly affected by the reinforcement (preform) structures. The textile preforms are designed such a way that it gives good mechanical properties, in-plane property, tailor ability, drapability, initial extension and bending properties to final product. The geometrical aspects of preform can provide the information regarding maximum packing factor, shearing behavior and bending behavior of laminate [1], [2], [5]. Textile preforms are subjected to the wide range of complex deformations, impact forces, during manufacturing process.

The preform selection should be such a way that it should not generate the void, which are responsible for propagating the cracks in final structures [3], [4].

In this project glass fibers with different structures like woven, bi-axial, multi-axial were used as textile reinforced materials. The properties like GSM, linear density, air-permeability, tensile strength, flexural rigidity etc. of glass material have been measured by using standards. The fabrication of glass preform laminates has been done by hand lay-up process and the mechanical properties like tensile strength, flexural and compression of glass laminates have been measured. In this article only behavior of multi-axial preforms has been explained.

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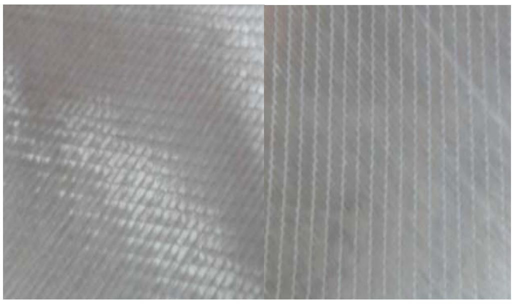
II. Material and Methodology

A. *Preform Sample*

The multi-axial glass fabrics GM0°,+45°: 0º,±45º CDB (Tricot) and GM90°,+45°: 90º,±45º DDB (Pillar) were procured from Arvind (Advanced Material Division), Ahmadabad. The multi-axial glass fabric consists of three layers with different laying direction and different stitch type as shown in Fig. 1.



(a) GM 0º,±45º CDB (Tricot) (b) GM 90º,±45º DDB(Pillar)

Fig. 1 Sample of Multi-axial Preforms

The properties of preforms like linear density, thread density, GSM, thickness and tensile strength have been measured. The effect of linear density and thread density of glass roving in final properties of preforms has been analyzed as in Table I. In multi-axial preforms the larger difference in GSM compared to thickness variation. The main reason for this behavior is due to correlation between linear density, thread density, number of layer and structure of preforms. The average value of linear density for both the multi-axial fabric found significantly low compare to plain, but due to the three layers in multi-axial it shows similar thickness and GSM value.

The GSM values of preforms have direct effect on weight of laminate. During the processing of laminate the amount of resin pour depends on the GSM value and percentage of glass in laminates [10], [11].

TABLE I
PROPERTIES OF PREFORMS

Sample	Degree	Linear Density [Tex]	Thread Density [Thread/ 10cm]	Thickness [mm]	GSM	Tensile Strength [mpa]
$G_{M0°,\pm45°}$	0°	2425.6	21			105.504
	+45°	1199.0	36	-	**1192**	75.504
	-45°	1029.7	36			84.000
Avg.		**1410.43**	**28.18 (28)**	**1.02**		**88.345**
$G_{M90°,\pm45°}$	90°	1392.2	42			113.946
	+45°	603.9	60	-	**1282**	95.582
	-45°	625.9	60			90.722
Avg.		**816.42**	**50.42 (50)**	**1.14**		**100.083**

B. *Fabrication of Laminates*

The hand laying process is one of the simplest processes for manufacturing the laminates. The polyester resin has been mixed with two chemicals cobalt and catalyst to improve the solidification of resin during impregnation. In every one kilogram of resin 0.5 ml of cobalt has been added as hardener.

Fig. 2 Hand Laying Process

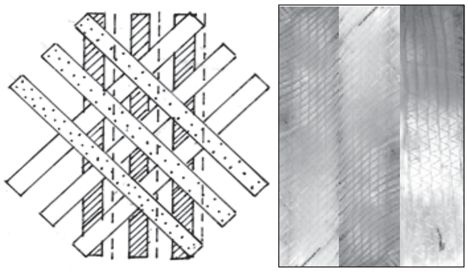
The laminates were fabricated by hand laying process using set up at Tulsi Fiberglass Industries, Vadodara as shown in Fig. 2.

II. TENSILE TESTING OF PREFORMS AND LAMINATES

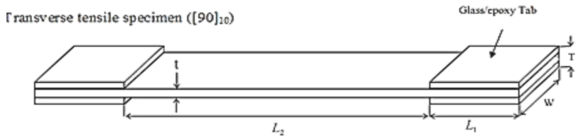
The testing of tensile strength of multi-axial glass preforms were performed by cutting the fabric in direction of laying of roving lay. The samples were cut in 0° direction and ±45° direction as shown in Fig. 3 [6], [7].

The sample is mounted on a machine as shown in Fig. 4. The gauges length has been kept 100 mm and the force applied axially at the constant rate of 80 mm/min and necessary data has been collected from the computer.

Experimental set up for mechanical tests is shown in Fig. 4. In this test glass fiber reinforced plies has been cut out from the laminates in both directions (longitudinal and transverse) according to ASTM D3039. In This work the specimens were cut in the direction of laying shown in Fig. 3.



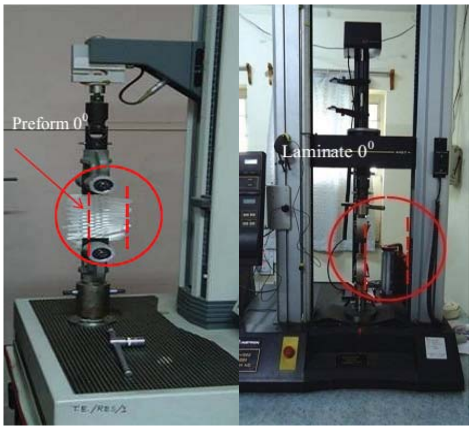
(a) Preform Sample



L1=Jaw Length=50mm, L2=Gauze Length=150mm T=Thickness, W=Width=25mm

(b) Laminate sample

Fig. 3 Sample Cutting of Preform and Laminate



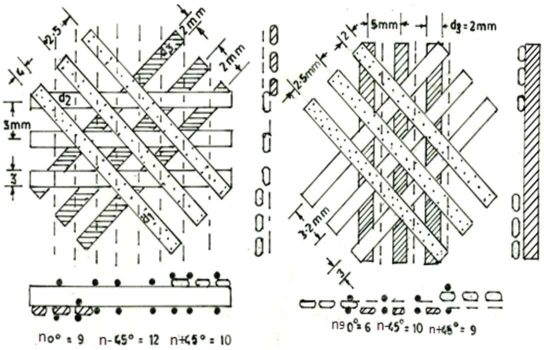
(a) Preform (b) Laminate

Fig. 4 Tensile Testing

III. STRUCTURAL ANALYSIS

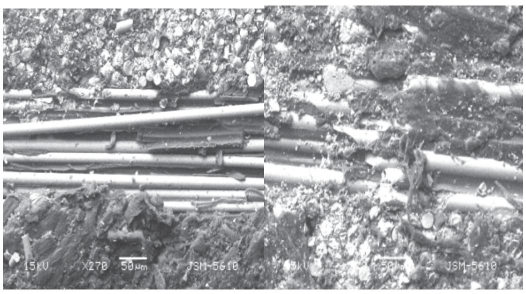
Multi-axial fabric is a multilayer fabric, bounded by chain or tricot stitch. The fabrics can have up to 8 layers and can also be added with chopped fibers or mat [8], [9].

In GM0°/+45° the bottom layer has been laid in -45° direction top layer in +45° and between top and bottom layer laid in 0° direction. Due to the 0° direction yarn laid between two crossing roving the good binding force existing between three layers and give stable structure. These preform having proper distribution of roving in all direction. The bottom and top layers have equal thread density and more than the central layer. Hence gives the compact structure, which easy to handle. Similarly in GM90°/±45° out of three layer the bottom has been laid in 90° direction and the top two layers in +45°/-45° direction. The top cross over layers provide better strength due to the stitch moving parallel to 90° roving with bottom layer, but due to that bottom layer of 90° it have tendency to distort. Also the thread density of the bottom layer seems to be a low and the distance between two roving is more as shown in Fig. 5. This structure contributes more in the strength but difficult to handle. Hence, the multi-axial fabric is a tailor made fabric which can engineered as per performance requirement of the final product due to flexibility in varying the structure by changing the fabric density, insertion angle, number of layers, thread density, direction of laying and can also combine the different materials in one single fabric with multilayer. Even due to the non-crimp structure it gives good mechanical properties and less cutting operation during laying of the preforms compare to woven fabrics.



GM0°/±45° GM90°/±45°

(a) Preform Structure



GM0°/±45° GM90°/±45°

(b) Preform Structure in Laminate

Fig. 5 Structure of Multi-axial Preforms and Laminates

The analysis has been done by consolidate this preform structure in laminate. In GM0°/±45° laminate the roving can see arranged in three different direction in all three layers. The 0° roving can be clearly seen in Fig. 5 (b), which separating top and bottom layer. TheGM90°/±45° consolidation seems good as no void generation.

A. DSC Analysis of Laminates

The sample of laminate has been taken for study to understand the degradation behavior using DSC 822 model. The result obtained shown in Fig. 6. The DSC curve has been obtained by heating the sample up to 500°C.

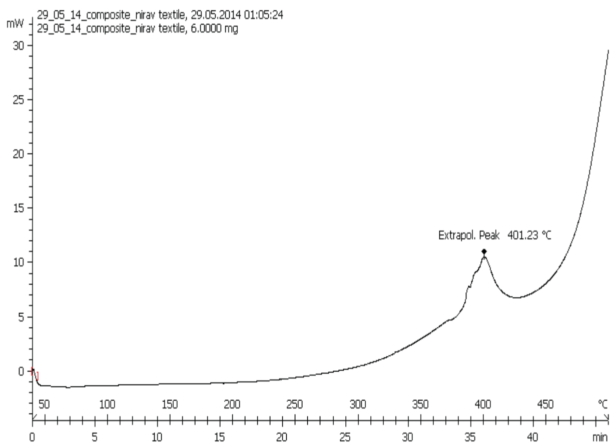


Fig. 6 DSC Analysis of Glass Laminate (G$_{M0°,\pm 45°}$)

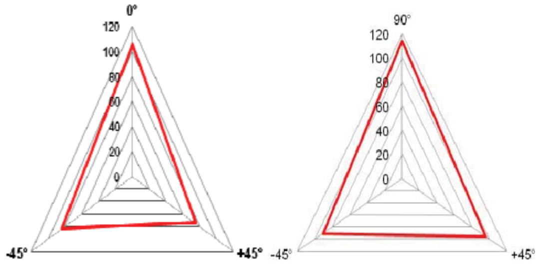
The sample was heated for 44 minutes in the suitable standard conditions. Fig. 6 shows that the sample remains in stable condition nearly at 250°C, after which the material start to degrade. The Laminate found suitable for resisting high temperature up to 400°C. The sharp peak at 401°C indicates that the complete degradation of the sample, during this maximum release in energy takes place; these indicates that after 250°C the molecular movement starts and the solid state material changing its phase and degrade.

B. Effect of Multi-axial Glass Preform Structure of Laminates Properties

The tensile properties of glass preforms is depends on yarn roving, linear density, thread density, number of layers, direction of laying of yarn, stitch density and GSM value.

The woven and biaxial preform structures were also analyzed during experiment. It has been observed that in woven fabric weave have no significant effects on strength for same GSM of twill preform due to non-crimp structure. In the bi-axial preform samples the number of threads contributes more in strength gives higher value of tensile strength. It has been observed during experiment the biaxial sample having yarn laying in 0°/90° direction shows less stability compared to yarn laying in +45°/-45° and also the GB+45°/-45° sample shows less distortion during testing.

The tensile properties of multi-axial fabrics are also depending upon linear density, yarn orientation and number of layers. The GM90°/±45° have lower value of linear density and higher value of thread density and the trend was exactly reverse in case of GM0°/±45° .The tensile strength of GM90°/±45° preform have significant higher value compared to GM0°/±45° due to the high value of thread density as shown in Fig. 8.



(a) GM 0°,±45 (b) GM90°,±45

Fig. 7 Tensile Strength of Multi-axial Preform

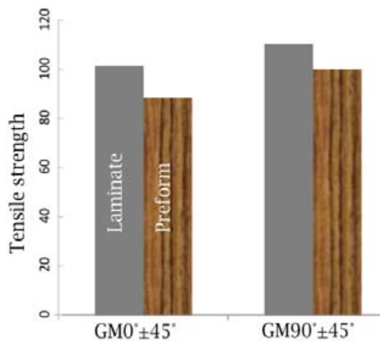


Fig. 8 Tensile Strength of Glass Preforms and Laminate

The contributions of roving laid in different direction also have effect on tensile strength of multi-axial fabric. In Fig. 7 (a) shows higher tensile strength in 0° compared to +45°/ -45°, this behavior was due to higher linear density of glass roving laying in 0°. The average value of tensile strength has been depends on cohesion between all three layers laid in different direction and binding force act on the layer due to stitch formation. Similarly in GM90°/±45° the tensile strength behavior have similar trend in all three direction even though linear density of the roving laid in 90° direction were higher as compared to ±45° , but due to having less thread density it balance the structure as shown in Fig. 7 (b).

The studies has been also investigated the effect of multi-axial glass preform structures and laminates on tensile strength, bending and compression properties of laminates. The two different multi-axial fabric GM 0o,±45 and GM 90o,±45 with similar GSM use to convert in to laminates.

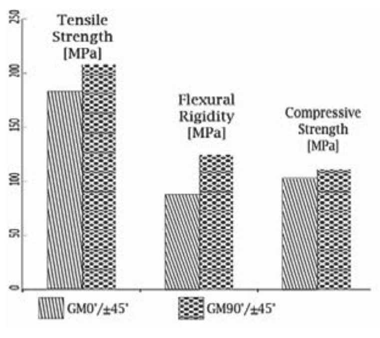


Fig. 9 Comparative Properties of Laminates

During investigation it has been observed that multi-axial preform shows higher value of tensile strength then woven, and biaxial. The plain preform has stable structure but having interlacement, which causes the distortion of yarn during the fabrication process. But multi-axial preforms layers remain in contact with each other by stitch formation give stable structure.

The resin gets completely abounded between the layers in multi-axial preform. In multi-axial GM90°/±45° shows better value for tensile and compression strength than GM0°/±45°, due to laying of yarn in 90° as shown in Fig. 9. The flexural rigidity and compression properties of laminates are depend on core material properties. The GM90°/±45° multi-axial laminates have higher values of tensile, flexural and compression properties.

IV. Conclusions

The structural and mechanical properties of preform and laminates were studied using standard methods. It has been observed that the glass fabric geometry, including type of weaves, warps and filling density and number of layer plays significant role in deciding mechanical properties of laminates.

The multi-axial fabric have tailor-made properties, due to which fabric density, insertion angle, number of layers, thread density, direction of laying can be combine in one single fabric with multilayer. The internal structure of multi-axial reveals the uniformity of matrix materials inside the preforms and also increase cohesion between layers, which improves the mechanical properties of laminates.

Thus it can be conclude from results that the mechanical properties of laminate greatly influence by structure of laminate. Hence designing accurate parameter of preform can give required quality of laminate.

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