Chapter 6

CONCLUSION AND FUTURE SCOPE

In this work, a detail study is conducted which includes weaving of Carbon fibre, preparation of textile polymer composite laminate (TPCL) by hand layup technique and effect of orienting differently fabric layers on mechanical properties. The work can be summarised as follows:

Effect of mechanical properties. The objective of this research work was to study the physical and mechanical properties of textile composite's laminates produced by orienting fabric layers differently.

To study properties of textile composite laminates, having fabric layers oriented differently three types of parameters were studied. To study the effect of orientation on textile composite laminate, the factors like number of layers, type of resin, curing time and temperature, squeezing pressure were kept constant. Three parameters studied in view of orientating the fabric layers differently were angle of orientation (skew angle), type of weave and type of reinforcement yarn. The properties studied were physical (density and fibre volume fraction) and mechanical (tensile, flexural, impact and damage resistance). The numerical values of this study are summarized and tabulated in Table 6.1. For comparison the mechanical strength values of steel and aluminum are also specified in the table.

I. **Effect of skew angle on the mechanical properties**. The skew angle has major effect on the mechanical properties i.e. tensile, flexural, impact and damage resistance.

1. The samples* S5 (CC5) and S1 (CC1) have maximum tensile properties like ultimate strength, modulus of elasticity, specific stress and specific modulus of elasticity in longitudinal and transverse direction respectively. While S3 (CC3) orientation have minimum tensile property in both longitudinal and transverse direction. The strength and modulus are reducing as the angle of fabric deviates from axis of loading.

* For detail specifications of samples S1, S2,…….S10 refer Table 3.3

2. The orientation S5 (CC5) and S4 (CC4) have maximum flexural strength and flexural modulus in longitudinal and transverse direction respectively. While S2 (CC2) orientation have minimum flexural strength and flexural modulus in both longitudinal and transverse direction.

3. The orientation S3 (CC3) have maximum impact strength in longitudinal and transverse direction respectively. The uniform distribution of fibres in all angles have better impact strength. While S2 (CC2) orientation have minimum impact strength and in both longitudinal and transverse direction.

4. The orientation S3 (CC3) have maximum damage resistance strength. Other than this orientation, S1 (CC1), S2 (CC2), S4 (CC4) and S5 (CC5) have similar strength.

II. **Effect of weave structure on the mechanical properties**. The weave structure like plain, twill and 4 end sateen were studied. Weave has effect on the mechanical properties i.e. tensile, flexural, impact and damage resistance.

1. The textile polymer composite laminate with twill weave S7 (CH2), and sateen weave textile laminate S8 (CH3), have maximum flexural strength and flexural modulus in longitudinal and transverse direction respectively. While, textile polymer composite laminate with sateen weave S8 (CH3), and plain weave S6 (CH1), have minimum flexural strength and flexural modulus in both longitudinal and transverse direction.

2. The plain weave textile polymer composite laminate S6 (CH1), have maximum impact strength in longitudinal and transverse direction respectively.

3. The plain weave textile polymer composite laminate S6 (CH1), have maximum damage resistance strength.

III. **Effect of type of reinforcement yarn on the mechanical properties.** Carbon, Kevlar and HDPE fibres are used to study the effect of type of reinforcement yarn on the mechanical properties i.e. tensile, flexural, impact and damage resistance. Type of reinforcement has effect on the mechanical properties of TPCL.

1. Ultimate tensile strength is maximum of orientation S1 (CC1) in both longitudinal and transverse direction. While, plain weave Carbon-HDPE textile composite laminate S6 (CH1) and Carbon-HDPE-Kevlar S10 (CK) have minimum tensile strength in longitudinal and transverse direction respectively.

2. Textile polymer composite laminate, Carbon-Carbon S1 (CC1) and Carbon-HDPE S6 (CH1) has maximum flexural strength and flexural modulus in longitudinal and transverse direction respectively. Textile composite laminate Kevlar-HDPE S9 (KH1) has minimum tensile strength in both longitudinal and transverse direction.

3. Textile polymer composite laminate, Carbon-HDPE S6 (CH1) and Carbon-Carbon S1 (CC1) have maximum impact strength in longitudinal and transverse direction respectively. Textile polymer composite laminate, Carbon-Carbon (CC1) and Kevlar-HDPE (KH1) have minimum impact strength in longitudinal and transverse direction respectively.

4. Textile polymer composite laminate, Carbon-Carbon S1 (CC1) have maximum damage resistance strength.

The research work can be summarized as orientation of fabric layers differently in view orientation angle (skew angle), weave structure and type of reinforcement has effect on tensile, flexural, impact and damage resistance properties of textile polymer composite laminate (TPCL)

SEM Analysis. Different forms of failure mechanism have been observed microscopically for different textile polymer composite laminate having all the three parameters of variation viz. skew angle, weave structure and type of reinforcement yarn for mechanical properties like tensile, flexural, impact and damage resistance. Different failure mechanism like fibre fracture, fibre pull out, matrix cracking, fibre/matrix debonding, fibre kinking, fibre splitting and delamination.

Numerical modelling: A numerical model (based on the finite element method) has been developed to predict the tensile behaviour of textile polymer composite laminate upon variation of orientation angle. Experimental tensile properties of the textile polymer composite laminate were used as input for the model; the measured and FEM values of tensile properties parameters like ultimate strength and strain are compared to assess the accuracy of the predictions.

The final goal is to optimize the effect of orientation angle (skew angle) on the tensile properties of the textile polymer composite laminate for different industrial applications without having to produce and test several prototypes.

This work points out that the properties of the composite structure depends completely on the orientation of fabric layers. The different orientation includes angle of laying, sequence of layer, weave structure and type of reinforcement yarn. Mathematical modelling provides estimates of optimum orientation of fabric to produce a specific composite required by a particular application consisting of different fibres and resins. This information can be used to provide, an estimate of desirable properties for a product, required in specific application without actual production of that product.

Application of textile polymer composite laminates.

Composites are one of the most widely used materials because of their adaptability to different situations, there is ample scope of design changes along with accessibility of materials and processes. For serving a specific purpose for an application, it exhibits desirable properties in terms of ease of combination with other materials. Application like aerospace, automotive, civil engineering and sporting goods demand products with specific properties and cost effectiveness.

Table 6.1: Comparison of mechanical properties of TPCL in both directions.

Sample code	PROPERTIES									
	Tensile					Flexural		Impact		Damage resistance Strength
	Orientation	Stress Ultimate strength	Modulus of Elasticity	Specific strength	Specific Modulus of Elasticity	Flexural strength	Flexural Modulus	Energy absorbed	Impact strength	
		Mpa	GPa	kN. m/kg		Mpa	GPa	Joules	kJ/m2	(N/mm)
Longitudinal										
CC1	(0/0/0/0)	268.98	5.475	201.50	4.10	260.39	0.26	**0.636**	**45.854**	730.33
CC2	(0/+30/-30/0)	202.43	5.164	152.37	3.89	235.42	0.24	**0.505**	**32.771**	747.69
CC3	(0/+45/-45/0)	175.7	5.134	131.83	3.85	274.42	0.27	**1.077**	**76.413**	795.25
CC4	(0/+60/-60/0)	239.45	5.471	180.06	4.11	312.49	0.31	**0.456**	**36.233**	741.14
CC5	(0/90/90/0)	456.73	7.292	340.79	5.44	386.95	0.39	**0.644**	**50.056**	723.91
CH1	(0/0/0/0)	45.6	0.303	40.15	0.27	52.03	0.05	**1.347**	**100.208**	644.51
CH2	(0/0/0/0)	38.48	0.178	31.58	0.15	80.2	0.08	**1.151**	**73.688**	550.58
CH3	(0/0/0/0)	32.08	0.167	25.52	0.13	51.26	0.05	**0.836**	**51.407**	517.55
CC1 *	(0/0/0/0)	268.98	5.475	201.50	4.10	260.39	0.26	**0.636**	**45.854**	730.33
CH1 *	(0/0/0/0)	45.6	0.303	40.15	0.27	52.03	0.05	**1.347**	**100.208**	644.51
CK	(0/0/0/0)	250.75	3.389	223.45	3.02	71.7	0.07	**1.054**	**79.449**	454.33
KH1	(0/0/0/0)	67.54	0.36	60.05	0.32	24.07	0.02	**0.828**	**52.543**	465.84
Transverse										
CC1	(0/0/0/0)	980.06	15.63	734.18	11.71	280.45	17.78	**0.953**	**81.336**	
CC2	(0/+30/-30/0)	401.01	7.524	301.85	5.66	187.18	12.78	**0.972**	**62.548**	
CC3	(0/+45/-45/0)	352.68	6.124	264.62	4.59	359.67	24.88	**1.506**	**99.906**	
CC4	(0/+60/-60/0)	365.78	7.179	275.06	5.40	567.77	56.83	**1.309**	**72.448**	
CC5	(0/90/90/0)	437	10.18	326.07	7.60	235.39	11	**1.481**	**98.287**	
CH1	(0/0/0/0)	242.4	3.691	213.42	3.25	394.08	25.76	**0.726**	**58.784**	
CH2	(0/0/0/0)	324.35	4.139	266.21	3.40	451.48	31.04	**0.773**	**46.541**	
CH3	(0/0/0/0)	369.75	4.345	294.13	3.46	457.86	28.11	**0.649**	**48.52**	
CC1*	(0/0/0/0)	980.06	15.63	734.18	11.71	280.45	17.78	**0.953**	**81.336**	
CH1 *	(0/0/0/0)	242.4	3.691	213.42	3.25	394.08	25.76	**0.726**	**58.784**	
CK	(0/0/0/0)	161.26	2.103	143.70	1.87	239.8	7.15	**0.958**	**71.016**	
KH1	(0/0/0/0)	182.88	2.594	162.59	2.31	157.75	3.54	**0.743**	**49.353**	
Steel	(ASTM 228)	-	-	204-428	-	-	-	-	-	
Steel	Stainless	-	-	63.1	-	-	-	-	-	
Aluminium	Alloy (7075-T6)	-	-	204	-	-	-	-	-	
Aluminium	Alloy (6061-T6)	-	-	115	-	-	-	-	-	

In application like aerospace and automobile the reduction of weight of materials along with high strength gives advantages in terms of fuel savings and overall mass reduction. This reduction in mass translates to reduced material and energy costs. So, the materials with specific strength becomes the best alternatives of metals. In these applications though use of composites is costly, the overall gain is better in long run as fuel running costs of 25% of total commercial airlines of total operating costs. These may include improved strength, stiffness, fatigue and impact resistance, corrosion resistance etc. In such application the textile polymer composite laminate having orientations such as S1 (CC1) and S5 (CC5) can be considered.

In marine application along with underwater vehicles improved impact strength and corrosion resistance along with other properties are also very importance in material selection process. Here, textile polymer composite laminate with orientation such as S3 (CC3) can be used.

In construction the properties like strength, corrosion resistance, environmental effect become important. Beyond mentioned criteria, affordability is also an important issue in majority of applications. High initial cost is not viable. In such applications hybrid textile polymer composite laminate such as Carbon-HDPE plain S6 (CH1), twill S7 (CH2), sateen S8 (CH3); Carbon-HDPE-Kevlar S9 (CK) and Kevlar-HDPE S10 (KH1) becomes possible. One such application is vehicle manufacturing where in costs associated with manufacturing, operating and disposal of the vehicle are high.

Selection guide for the material: This work has generated a knowledge which guides the user to select properly hybridized and oriented composite to exhibit the desirable performance from the product. This selection guide aimed at aiding potential users to determine the orientation of fabric selection of the most logical composite, and then analyzing hybridization and costs. Available information from various literature sources, material suppliers along with data generated in this work will be useful to the potential and existing composite users. Since decades, researchers such as Moon et al., [184] have focused their research in composite materials on aerospace engineering.

Table 6.2: Material selection chart for different applications

Application	Required properties											
	Ultimate tensile strength	**Tensile Modulus of Elasticity**	**Tensile Specific strength**	**Tensile Specific Modulus of Elasticity**	**Flexural strength**	**Flexural Modulus (Bending stiffness)**	**Impact Strength (Toughness)**	**Damage resistance Strength**	**Cost effectiveness**	**Corrosion resistance**	**Temperature**	**Samples recommended**
Aerospace												
Wings					✓	✓	✓				-30°C	CC1, CC5
rudder	✓	✓	✓	✓				✓			-30°C	CC1, CC5
Floor beams	✓	✓	✓	✓	✓	✓	✓				Atmospheric	CC1, CC5
Automobile												
Car body					✓	✓	✓	✓	✓		Atmospheric	CC1, CH1
Bumper beam					✓	✓	✓	✓	✓		Atmospheric	CH2, CK
Valance panels	✓	✓	✓	✓			✓		✓			CK
Carpet									✓			CH2
Civil engineering												
Bridge	✓	✓	✓	✓					✓	✓		CC1, CH1
Roof structure	✓	✓	✓	✓	✓	✓			✓		Atmospheric	CK
supports	✓	✓			✓	✓			✓		Atmospheric	CK
Marine												
Under water vehicles						✓	✓	✓		✓	Atmospheric	CH2
Hull							✓	✓			Atmospheric	CC5,CH1,CK
Sporting goods												
Golf sticks	✓	✓	✓	✓			✓				Atmospheric	CC1, CC5
Tennis rackets	✓	✓	✓	✓			✓					CK
Bicycle	✓	✓	✓	✓	✓	✓	✓		✓			CK

But new applications are opening up in various fields where either weight or resistance to corrosion or both are critical. Such suggested applications are marine, chemical processing industries and underwater structure etc.

Table 6.2, is a material selection chart, prepared to consider the possible application of the textile polymer composite laminate. This table gives a brief idea of selecting proper textile polymer composite laminate for specific application on the basis of properties required. The images of certain probable applications have been shown in the Figure 6.1.

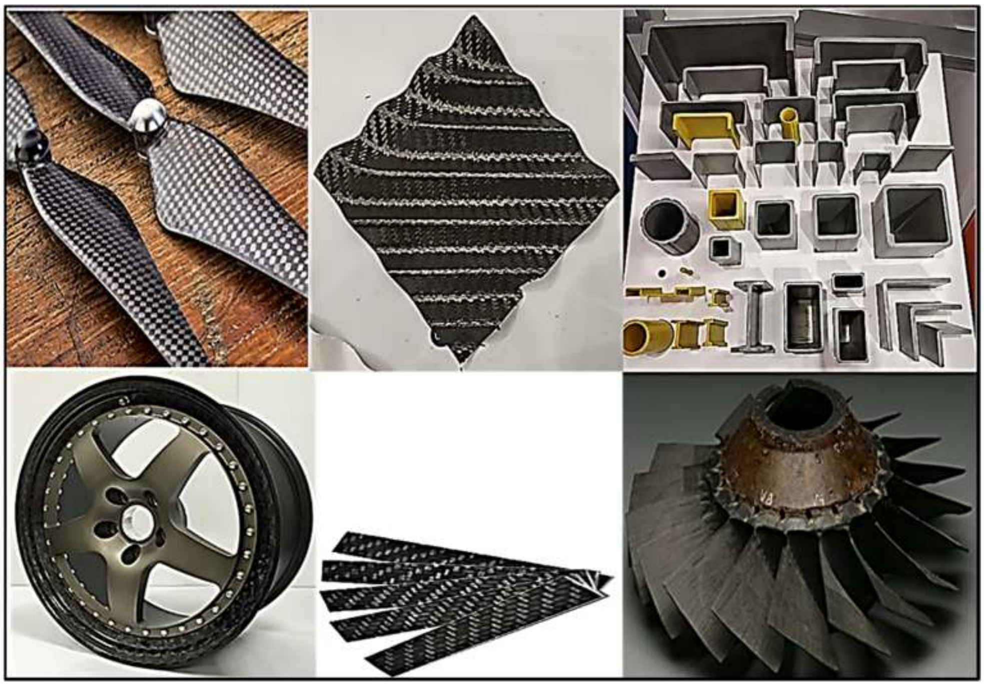

Figure 6.1: Suggested applications of the TPCL prepared

Future scope of work.

1. This work is to study textile composite laminates which are produced by orienting the fabric layers differently. The study is confined to four number of layers having same epoxy matrix. The encouraging results give scope to investigate further:
    a. The study can be extended by increasing number of layers
    b. The study can be added with other fabrics made from natural fibres like jute, hemp, banana and bamboo etc.

c. The other properties like interlaminar shear, strength perpendicular to axis, shear, resistance to ballistic impact, compressive strength etc.

d. Strength of single laminate having layers at angle like ±15°, ±30°, ±45°, ±60°, ±75° and ±90°.

2. In this work impact strength was studied in terms of quasi static indentation test. For this test the shape and size of indent was kept same of bullet. The study may be extended which corelate this results with high velocity ballistic impact test. This study will able to predict costly and clumsy high velocity test results by performing a simple quasi static indentation test.

3. In this work the numerical model is developed to predict the tensile strength of hybrid composite consisting of four layers as described in chapter 5. Here, interlaminar strength was considered infinity. The data of actual interlaminar strength are collected and model may be developed so that the simulation will be more realistic.

4. There is scope to investigate and develop model with varied number of layers, thickness, angle of laying, type of reinforcement yarn and matrix type.