CHAPTER 4

CONDUCTIVE HYBRID YARN

Application Base Study on Conductive Hybrid Yarns for Thermoplastic Composites

4.1 INTRODUCTION

An outstanding feature of the technical textiles industry is the range and diversity of raw materials, processes, products and applications that it encompasses. Conductive textile product is the one of the smarts area of the Technical textiles, which deals with the Electrical and Electronics related applications. Thermoplastic composites used in the electrical and electronic equipments are an important application area of the conductive textiles. These composites get special importance due to their outstanding electrical characteristics. The different electrical characteristics, which should be considered for the thermoplastic composites, are dielectric strength, surface resistivity, volume resistivity, dielectric constant, dissipation factor, electrostatic discharge, electromagnetic shielding effectiveness etc. Among these the dielectric strength and resistivity are important characteristics for applications of the thermoplastic composites.

In the present study, conductive thermoplastic composites are manufactured from conductive hybrid yarns made by Hollow Spindle technique. These yarns are used to make knitted fabrics to be used as preform. The preforms are converted into laminates by the Hot Press process. These laminates are assessed for various electrical properties viz. dielectric strength, surface resistivity and volume resistivity.

4.2 OBJECTIVE

In technical application of textiles, the final and functional properties of products depend on requirement of the end use application. Thus raw material requirement and composition of different material in hybrid yarn is also based on its end use. In manufacture of textile composite the major problem is to get uniform distribution of thermoplastic melt into tightly woven textile preforms. In this respect the thermoplastic matrix needs to incorporate into reinforce fibre strand at the initial stage. To get conductive effect in thermoplastic materials, certain processes are developed to incorporate electrically conductive additives including carbon black powder, carbon fiber, metallic fiber, metal-coated carbon fibre etc. These processes are complex and difficult to control due to deposition of carbon powder, which demands high maintenance of processing machine. The hybrid cover yarn incorporating thermoplastic material(PP) in the form of filament with reinforce filament (Glass) and conductive material(Copper wire) in yarn is one of the solutions. So this work is mainly emphasizing the process of incorporating copper wire in hybrid yarn to form laminates in one step process.

The main objective is to develop the conductive hybrid yarn for application in composite. Further prepare the knitted fabric prforms to make the laminat product. Also evaluate the laminates for its dielectric strength, volume resistivity, flexural strength and tensile strength.

4.3 EXPERIMENTAL PROCEDURE

In the present study, conductive thermoplastic composites are manufactured from glass/polypropylene/copper hybrid yarns made on Hollow Spindle Machine. The machine set up, specification of raw material and sample preparation methodology has been discussed in following section. Samples are mainly prepared in three forms i.e. Yarn, Fabric and Laminate.

4.3.1 Preparation of Conductive Hybrid Yarn

Five different parant yarns have been selected for preparation of various type of conductive hybrid yarns. The properties of these parent yarns used in the sample preparation have been listed in Table 4.1. Two multifilament polypropylene yarns; of 840 denier and 1000 denier have been used as thermoplastic material. Other specialty technical yarn viz. glass and copper are also used as reinforcing and conductive materials respectively. The hollow spindle machine(laboratory scale model) as described in Chapter 3 has been

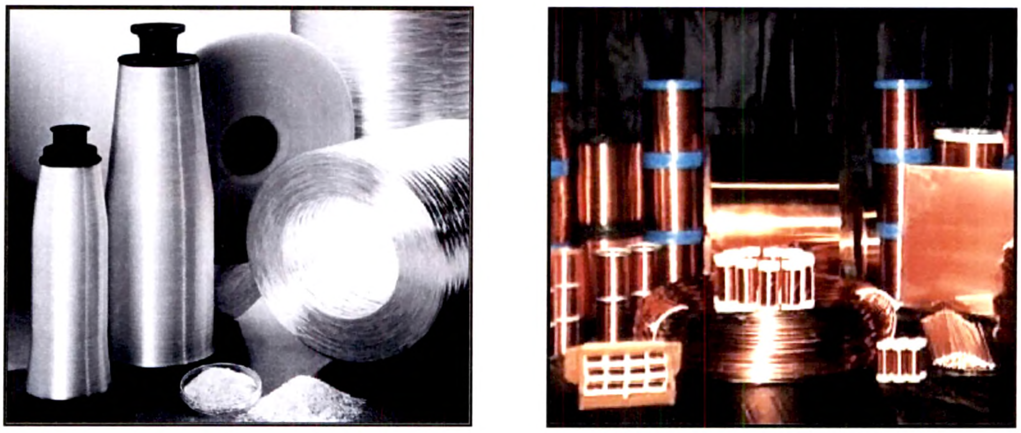

Fig. 4.1 Glass and Copper yarn packages used for hybrid yarn preparation

Table 4.1 Specifications of Various Parent Yarns Used for Hybrid Yarns

Sr. No.	Type of parent yarn	Code	Linear density		Number of filament	Density g/cm^3	Tenacity (cN/tex)	Extension (%)
			Denier	Tex				
1	Polypropylene	P_1	840	93.33	144	0.90	26.55	35
2	Polypropylene	P_2	1000	111.11	144	0.90	47.34	24.76
3	Glass	G	1395	150	360	2.54	44.01	2.20
4	Copper 40 gauge	C_1	98	10.8	Mono	8.96	38.42	22.95
5	Copper 44 gauge	C_2	43	4.7	Mono	8.96	40.04	18.95

used to produce conductive hybrid yarns. The schematic diagram showing the material flow through hollow spindle machine is shown in Fig. 4.2. The glass filament and copper wire pass through the centre of hollow spindle and move upward to the take up device. The polypropylene filament wrapping is imparted by the rotation of double flange bobbin mounted on the spindle. The number of wraps per unit length of yarn depands on the spindle speed and yarn take up speed. The procedure to calculate the amount of wraps is as follows (see Fig. 3.4).

1) Spindle speed = 1440 x 152.5 / 22.5

= 9760 rpm

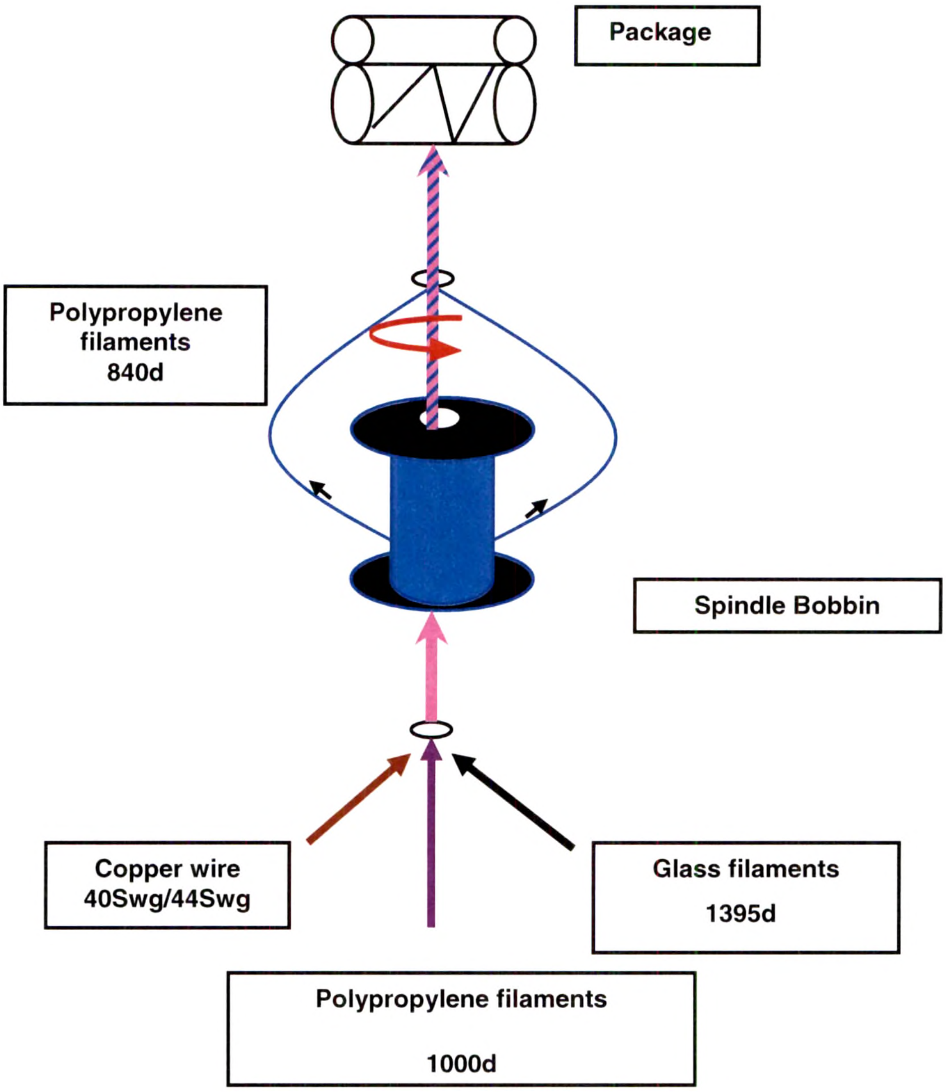

Fig. 4.2 Material flow through the hollow spindle machine

2) Yarn delivery speed (with A = 60T and B = 20T)

= 1440 x (152.5 / 305) x (4 / 36) x (60 / 20) x (20/30) x 3.14 x 0.08

= 40.19 m/min

3) TPM
$$= \frac{\text{Spindle speed (rpm)}}{\text{Yarn delivery speed (m/min)}}$$

$$= \frac{9760}{40.19} = 242.83$$

Thus the conductive hybrid yarns are made with about 243 wraps/meter at yarn delivery speed of 40 m/min.

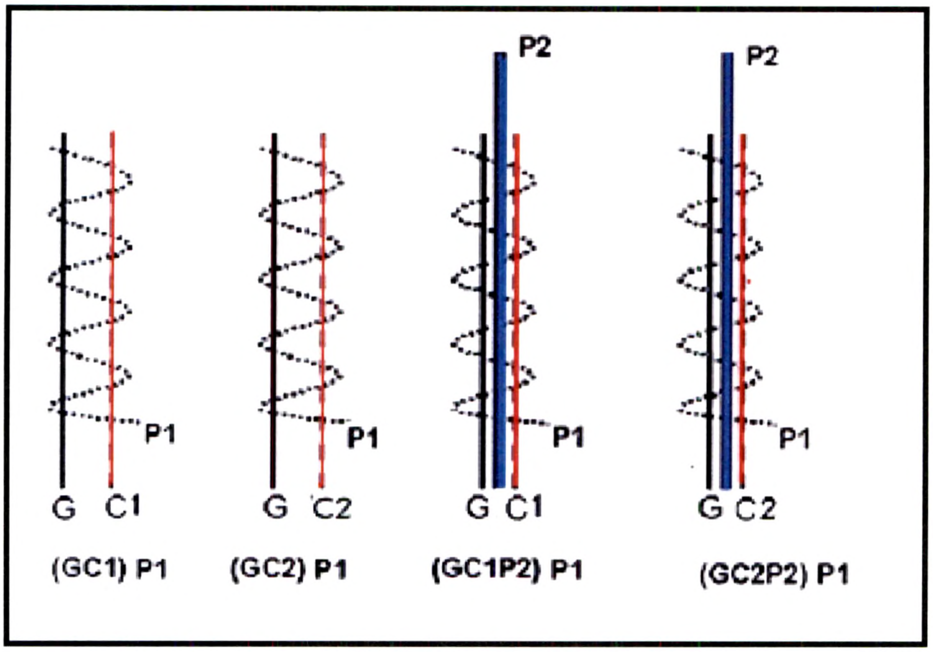

Fig. 4.3 Schematic model of hybrid yarn structures

Table 4.2 Specifications of Conductive Hybrid Yarns

Sr. No.	Conductive hybrid yarn	Filament in core	Filament in sheath	Liner density (denier)	Code
1	Glass/PP	Glass +Copper	PP	3222	$(GC_1)\ P_1$
2	Glass/PP	Glass + Copper	PP	2691	$(GC_2)\ P_1$
3	Glass/PP	Glass + Copper +PP	PP	4338	$(GC_1P_2)\ P_1$
4	Glass/PP	Glass + Copper +PP	PP	3735	$(GC_2P_2)\ P_1$

The four type of hybrid yarns samples have been prepared using different types of polypropylene, glass filaments and copper wire (Table 4.2). The glass filaments and copper wire are incorporated in the core in all the four samples. Whereas polypropylene is kept either in core or in sheath as the case may be (Fig.4.2). The schematic models of all these yarns are shown in Fig.4.3.

4.3.2 Preparation of Hybrid Yarn Conductive Fabric

Knitted fabrics samples have been prepared using the flat bed hand-knitting machine as shown in Fig. 4.4. The various features of this machine are:

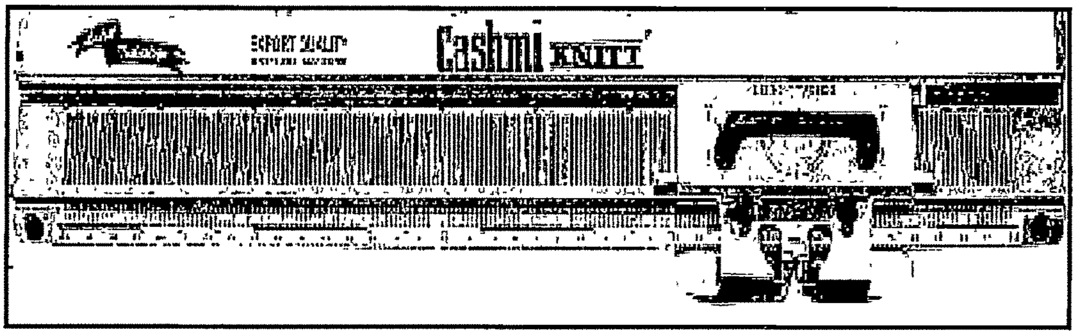

Fig. 4.4 Flat bed knitting machine

- Semi-automatic with stainless steel bed.
- 200 needles bed with 4.5mm pitch.
- Formation of patterns with knitting dial.
- Plating yarn feeder and carriage release mechanism.
- Capable of knitting plain, zigzag slip and plating design.

Four preform fabric samples have been prepared using each type of the conductive yarn. Main fabric parameters viz. courses/inch and wales/ inch are kept same for all these fabrics. The fabric thickness is measured using thickness gauge in each case. These specifications are given in Table 4.3.

Table 4.3 Specifications of Knitted Preforms

Fabric code	**F_1 (GC_1) P_1**	**F_2 (GC_1 P_2) P_1**	**F_3 (GC_1) P_1**	**F_4 (GC_2P_2) P_1**
Type of conductive yarn	(GC_1) P_1	(GC_1P_2) P_1	(GC_1) P_1	(GC_2P_2) P_1
Courses/inch	16	16	16	16
Wales/inch	7	7	7	7
Thickness (mm)	1.36	1.76	1.24	1.71

4.3.3 Preparation of Laminate

The composite or laminates are made from these knitted preforms fabrics using Hot Press machine shown in Fig. 4.5. The various specifications of this machine are as follows:

- Make: Perfect Hydraulic Engineering Co.
- Capacity: 60 tons
- Stroke: 200 mm

Fig. 4.5 Hot press machine set up

- Die height: 400 mm
- Plate Size: 475 mm x 475 mm
- Speed: 140 mm/min

Compression molding process is generally used for manufacturing thermo-set or thermoplastic composites. The samples of composites have been prepared at Electrical Research and Development Association (ERDA), Baroda.

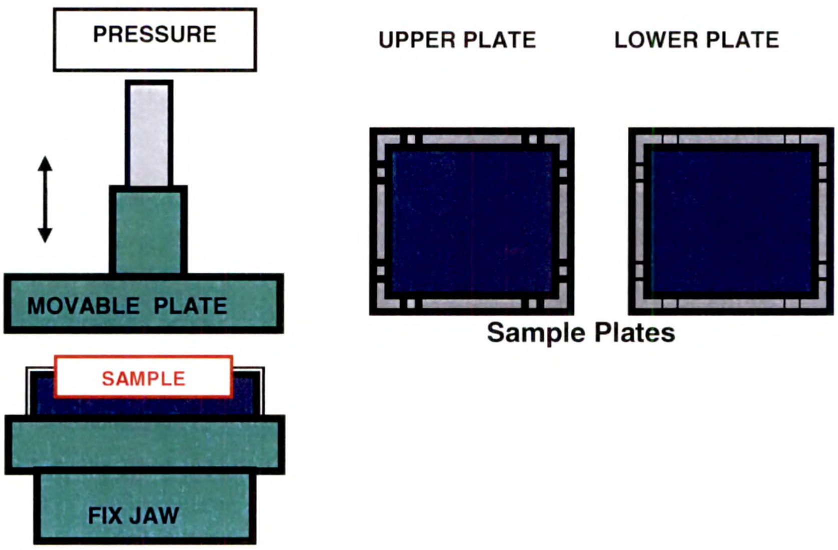

Fig. 4.6 Hot press machine outline

As shown in Fig. 4.6, the hot press machine fabric preform is placed between the mold plates and then pressure is applied gradually by hydraulic press mechanism. The mold is electrically heated to initialize cure reaction to consolidate glass content with the thermoplastic polypropylene filament to form the composite sheet. During the molding, the temperature is maintained at about 170^0C. The sheet laminates samples of 2.5mm thickness have been prepared by putting 2 or 3 layers of the same fabrics at the compressive load of 10 kg/cm^2. The composite samples are allowed to solidify at room temperature for about 5 hours.

4.3.4 Testing of Conductive Yarn, Preforms and Laminates Properties

a) Yarn Testing

The four types of conductive hybrid yarns prepared from glass, polypropylene and copper wire have been tested for its physical properties like linear density, tensile strength, and elongation at break. The standard test methods are used for evolution of there characteristics. The details of equipments and methods are same as described in Chapter 3.

b) Preforms Fabric

1) Fabric Thickness

Fabric thickness is measured using Thickness Gauge Mitutoyo, Japan having range of the thickness 0.01-10mm (Fig. 4.7). As per standard test method, the pressure foot and anvil should be cleaned and then gauge is set to zero. The

Fig. 4.7 Thickness gauge

pressure is given to press pressure foot on fabric. The thickness value is read from the dial of the instrument when pointer moment stops. Total of five readings from different place on the fabric specimen have been taken for each fabric sample to obtain the average thickness

2) Courses/inch and Wales/inch

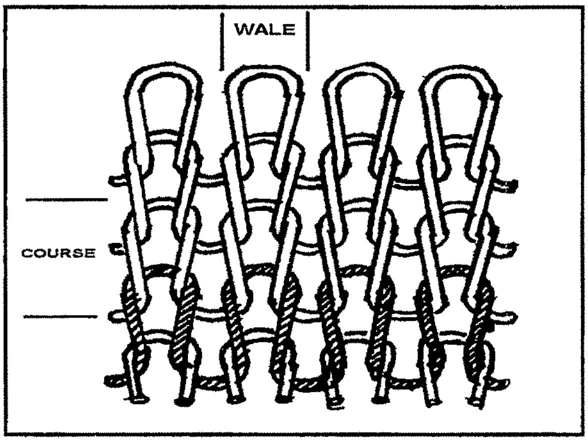

Fig. 4.8 Knitted fabric structure

The main structural parameter of knitted fabric i.e. Courses/inch and Wales/inch are measured using Pick Glass. Ten readings have been taken for each sample at different positions of the fabric and the average values have been reported. Fig. 4.8 shows the fabric structure of the knitted specimen showing the arrangements of courses and Wales. The fabric specimen was first spread over the template and then the pick glass is placed on the fabric. Numbers of courses and wales in unit length have been counted.

c) Laminate (Composite sheet)

1) Tensile and Flexural properties

The tensile strength and flexural rigidity of the laminates have been measured according to ASTM D 638 for tensile and ASTM D 790 for flexural properties using Universal Testing Machine at ERDA laboratory as shown in Fig. 4.9.The test specimen is positioned vertically in the grips of the machine to test tensile strength. The grip are tightened evenly and firmly to prevent any slippage. Traverse rate and the machine was set 0.2in/min. The elongation of specimen is continued until a rupture of the specimen breaking load and elongation at break were recorded

The flexural strength is the ability of the material to withstand bending forces applied perpendicular to its elongation axis. The same universal testing machine is used, for the measurement of flexural strength. The three-point loading system utilizing center loading on a simply supported beam is used.

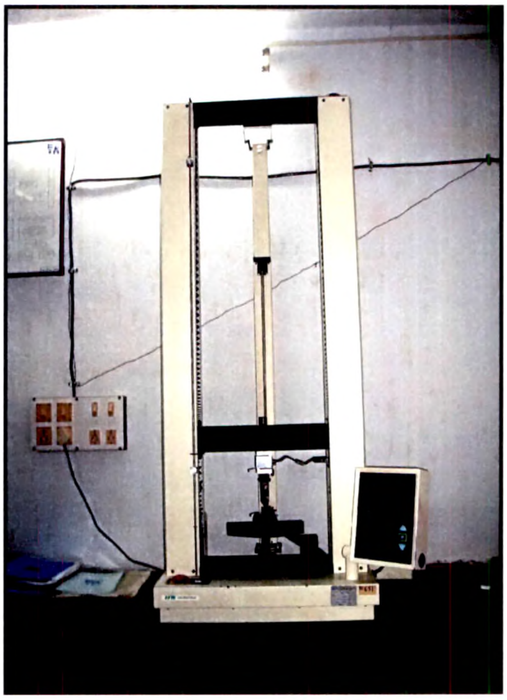

Fig. 4.9 Universal testing machine

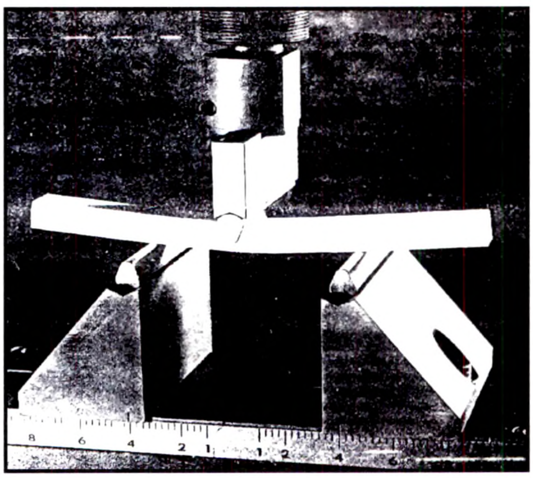

Fig. 4.10 Sample mounting for flexural test

A bar of rectangular cross section rests on two supports and is loaded by means of a loading nose midway between the supports. The maximum axial fibre stress occurs on a line under the loading nose. A mounting of specimen is shown in Fig. 4.10.

2) Dielectric Strength

The principle of measurement of dielectric strengths is shown in Fig. 4.11. The dielectric strengths of the various laminates have been measured according to ASTM D149-97a method, which uses base electrodes of 75mm diameter and top electrode of 25mm height X 25mm diameter connected with 0-50 Kv transformer with electric panel make Fig. 4.12 shows details of the set-up made by Allied Electrical Engineering Co.

The dielectric strength is the voltage gradient at which dielectric failure of insulating material occur under specific conditions of test. To test the specimen the alternating voltage, at a commercial power frequency is applied to a test specimen. The voltage is increased to breakdown voltage using the pair of electrodes mounted on either sides of specimen. Breakdown voltage readings are noted. Ten such tests for each sample have been carried out. The average dielectric strength is calculated using breakdown voltage and the laminate thickness.

$$\text{Dielectric strength (KV/ mm)} = \frac{\text{Breakdown Voltage(V)}}{\text{Thickness (mm)}}$$

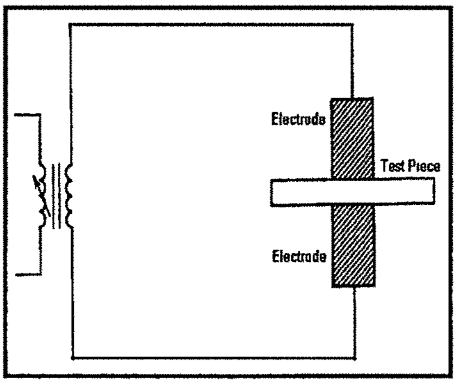

Fig. 4.11 Principle of measurement dielectric strength

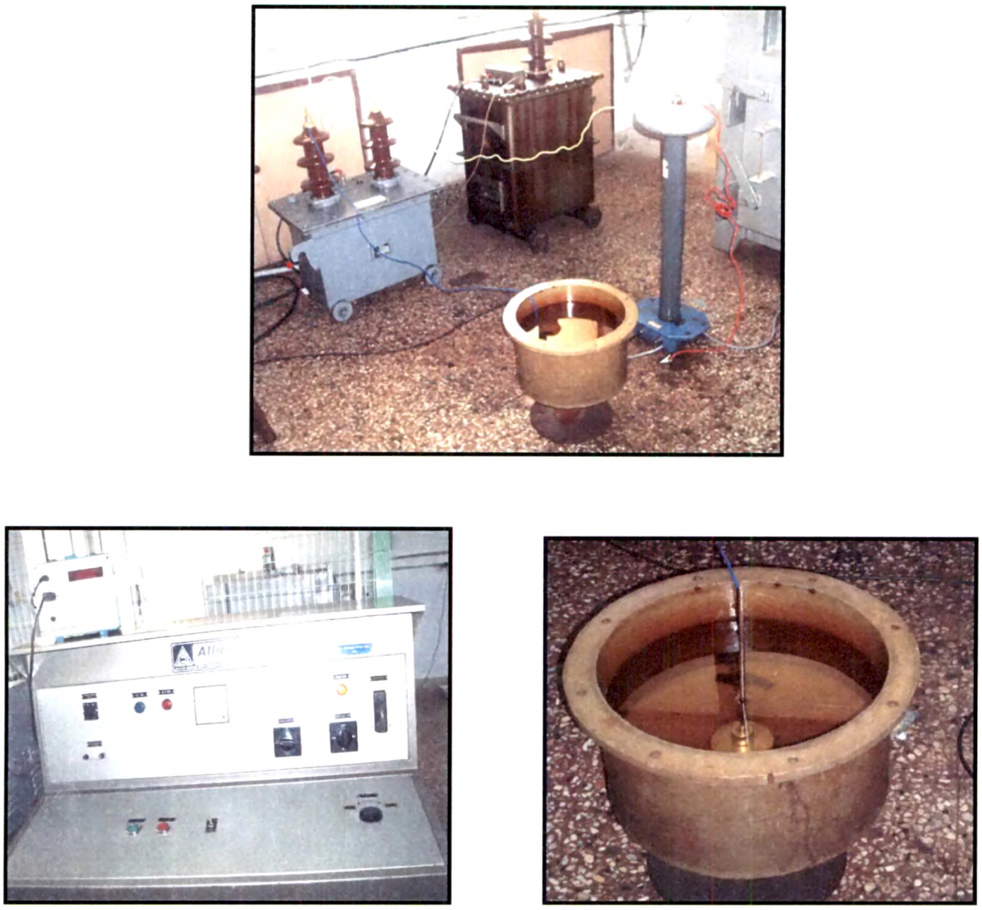

Fig. 4.12 Set up for measuring dielectric strength

3) Resistivity

The most desirable characteristics of an insulator is its ability to resist the leakage of the electrical current. The higher the resistance, the better is the insulator. The resistivity is measured in terms of surface resistivity and volume resistivity.

Volume resistance is defined as the ratio of the direct voltage applied to two electrodes that are in contact with specimen to that portion of the current between them that is distributed through the volume of specimen. It is given by the expression: Volume Resistivity (Ω / cm) = A/t (R_v), Where A=area; t=thickness of the specimen; Rv = Volume resistance.

Similarly, the surface resistances of a material is defined as the ratio of the direct voltage applied to the electrodes to that portion of the current between

Fig. 4.13 High resistance meter(Model: 4329 A)

them that is primarily in a thin layer of moisture or other material that may be deposited on the surface.Both of these properties are measured according to the ASTM D 257 method. These test methods cover direct current procedure for determining the both resistivity of electrical insulating materials or the corresponding conductance and conductivities. The High Resistance Meter(Model: 4329 A), with 16008A resistivity cell has been used to measure these properties(Fig. 4.13).

4.3.5 Scanning Electron Micrograph

To analyze textile material the photo-image must be magnified many times in order to study the surface features and other important characteristics. Due to the great depth of focus of the SEM, more information can be obtained about the nature of finished applications, fiber fracture, yarn structure, fabric wear, chemical degradation, abrasion, fatigue and many other aspects. The fibre distribution in final laminates made from hybrid yarn is studied using Scanning Electron Micrograph(Fig. 4.14).

The Scanning Electron Micrograph model JSM 5610LV with energy dispersive analytical X–ray (EDAX) has been used for the analysis of hybrid yarn and laminates. The Micrograph has magnification range upto X 3,00 000 and image resolution up to 3.0 nm in high vacuum and 4.5nm in low vacuum. The fine collimated beam of electrons is deflected through a suitable scanning coil

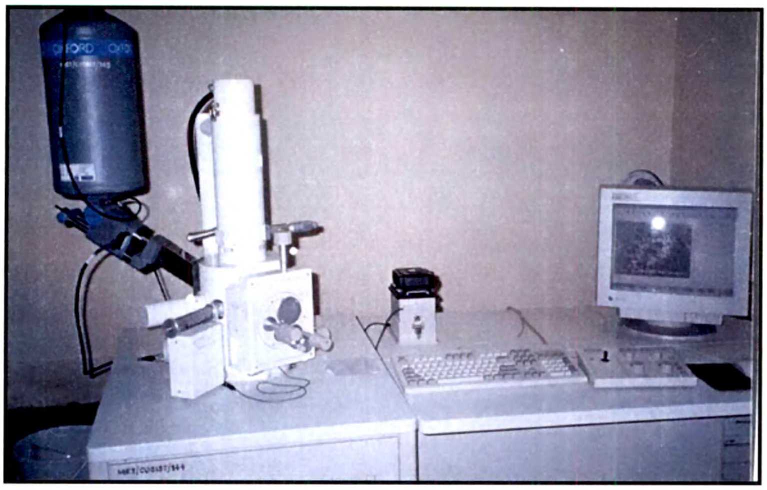

Fig. 4.14 Scanning electron Micrograph

device, so that it falls on different areas of the specimen surface at different moments of time. The circuit for detection of reflected beam is synchronized with the initial scanning coils to defect the reflected beam from each area of the specimen surface at respective moment of time and finally it forms an image on florescent screen which appears in continuous and stable forms. The SEM microscope is used for the study of filament damage, the homogeneity of filament and analyzing the distribution of component yarn in laminates cross section.

4.4 RESULTS AND DISCUSSION

In the present study, as stated in experimental procedure, various conductive hybrid yarn sample with different copper and polypropylene have been produced to study the effect of various conductive material on final composite characteristics. The test results of various yarn properties and laminates properties are analyzed. The structure is studied with help of scanning electron micrograph (SEM) to see the distribution of different components in the final laminate.

4.4.1 Conductive Hybrid Yarn Properties

The various physical and mechanical properties of conductive hybrid yarns have been given in Table 4.4

Table 4.4 Various Properties of Parent Yarn and Conductive Hybrid Yarn

Sr. No.	Type of Yarn	Linear density		Breaking load (gf)	Elongation (mm)	Tenacity (cN/ tex)	Extension (%)
		Denier	Tex				
Parent Yarn							
1	Polypropylene (P_1)	840	93	2478	105	26 55	35
2	Polypropylene (P_2)	1000	111	5260	74.28	47.34	24.76
3	Glass (G)	1350	150	6822	6.61	44.01	2 20
4	Copper (C_1-40)	98	11	418	68 85	38.42	22 95
5	Copper (C_2-44)	43	5	191	56.85	40.04	18 95
Conductive hybrid yarn							
1	(GC_1) P_1	3222	358	8190	9.21	31.74	3.07
2	(GC_2) P_1	2691	299	8010	9.85	26 78	3 28
3	(GC_1P_2) P_1	4338	482	9998	10.23	20.72	3.41
4	(GC_2P_2) P_1	3735	415	9820	10 11	23 66	3 37

a) Linear Density

The linear density of each component yarn viz. glass, polypropylene and copper is given in Table 4.4. Four different hybrid yarns are prepared with different combinations of component yarn. The final linear density of hybrid yarns depend on core yarn denier, sheath yarn denier and wrap density. It can be observed from Fig. 4.15 that maximum contribution in change in linear density is due to change in component yarn or introduction of more than one core component. In all four samples the wrap yarn component is same with same number of wraps. So in sample (GC_1P_2) P_1 and (GC_2P_2) P_1 final yarn denier is more due to polypropylene introduced in core along with glass. These changes in component yarn have significant effect on final composite properties.

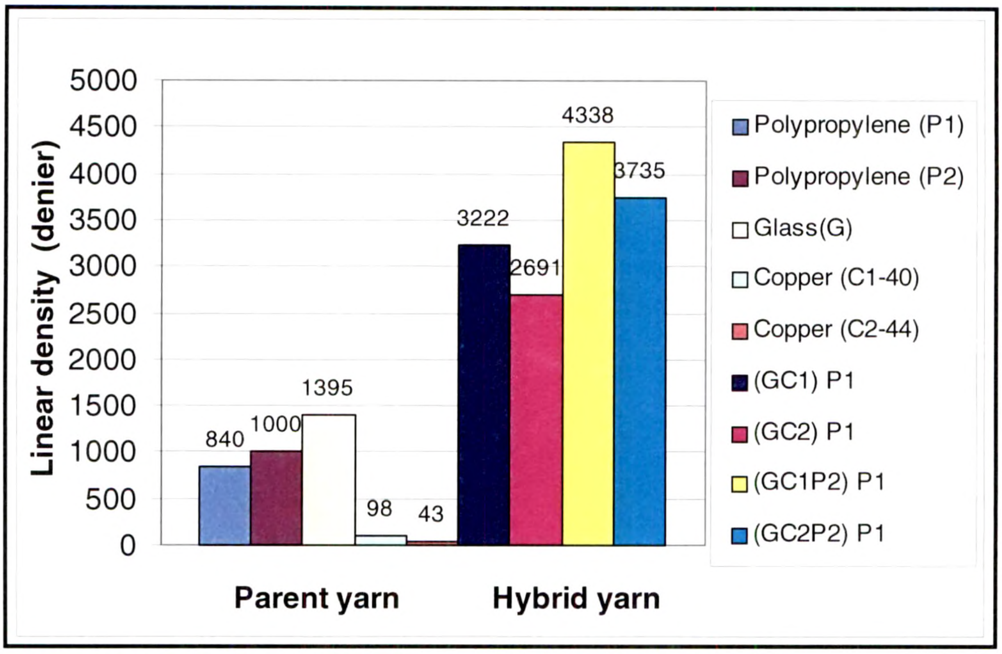

Fig. 4.15 Linear density of various conductive hybrid yarns

b) Strength and extension properties of conductive hybrid yarn

The hybrid yarn samples are produced by hollow spindle technique having core and sheath structure. The core yarn components mainly contribute in yarn strength and wrap yarn in extension properties of yarn. The Fig. 4.16(a), Fig. 4.16(b) and Fig. 4.16(c) shows comparative value of breaking load, extension and tenacity values of parent yarn and conductive hybrid yarns respectively.

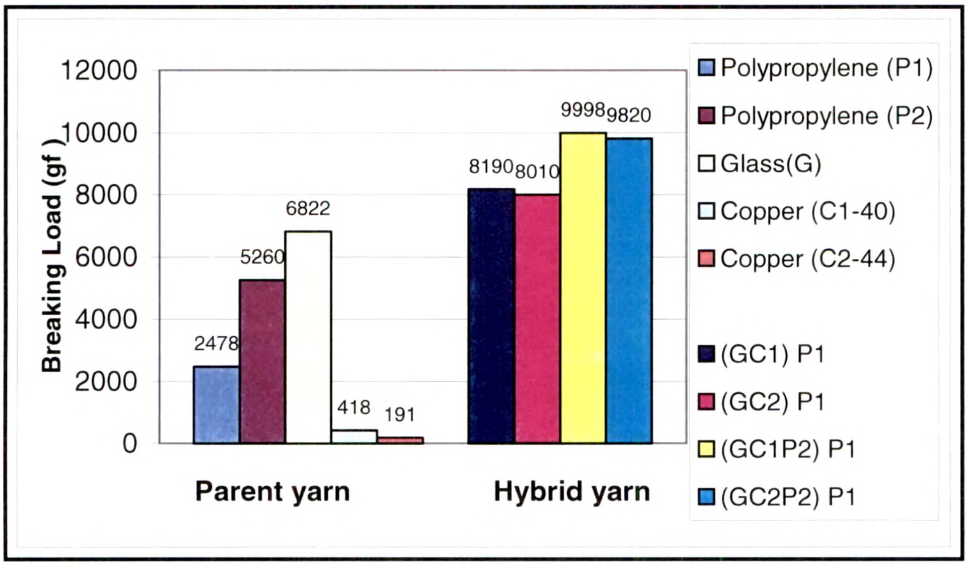

Fig. 4.16 (a) Breaking load of parent and conductive hybrid yarns

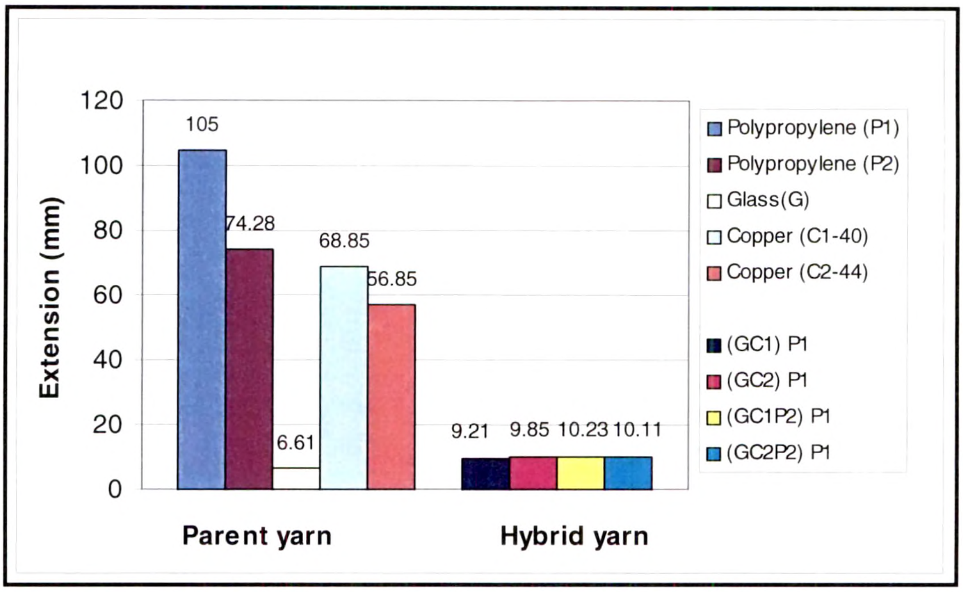

Fig. 4.16 (b) Breaking extensions of parent and conductive hybrid yarns

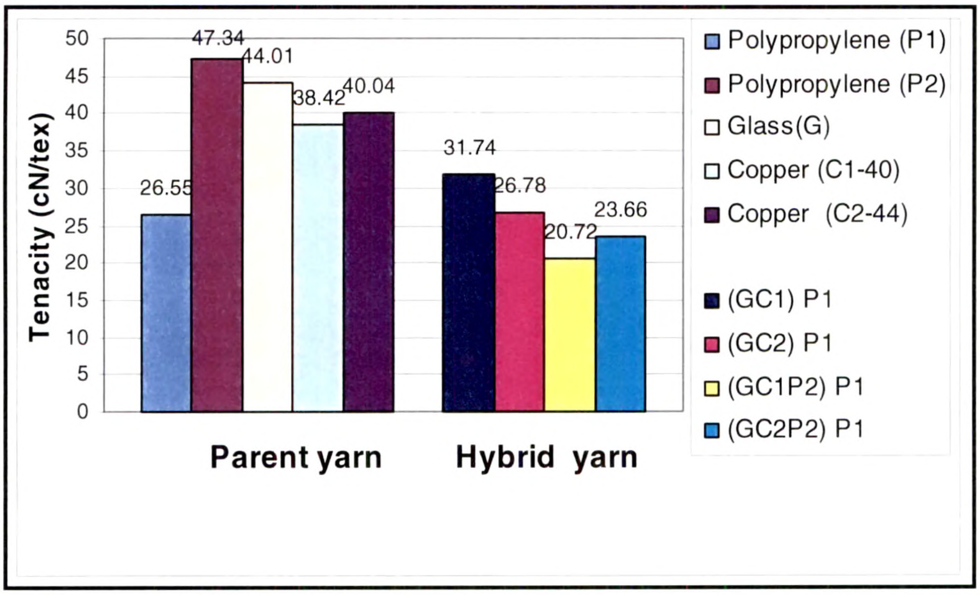

Fig. 4.16 (c) Tenacity of parent and conductive hybrid yarns

It can be seen from Fig. 4.16(d) that in all the cases there is an increase in the breaking loads of the conductive hybrid yarns. If we compute the contribution of the component yarns at the breaking elongation of conductive hybrid yarn, as given in Table 4.5, it can be seen that the wrapping contributes to about 15 % increase in strength of the conductive hybrid yarns. The Breaking elongation of all the conductive hybrid yarns is about 10mm for all the yarns.

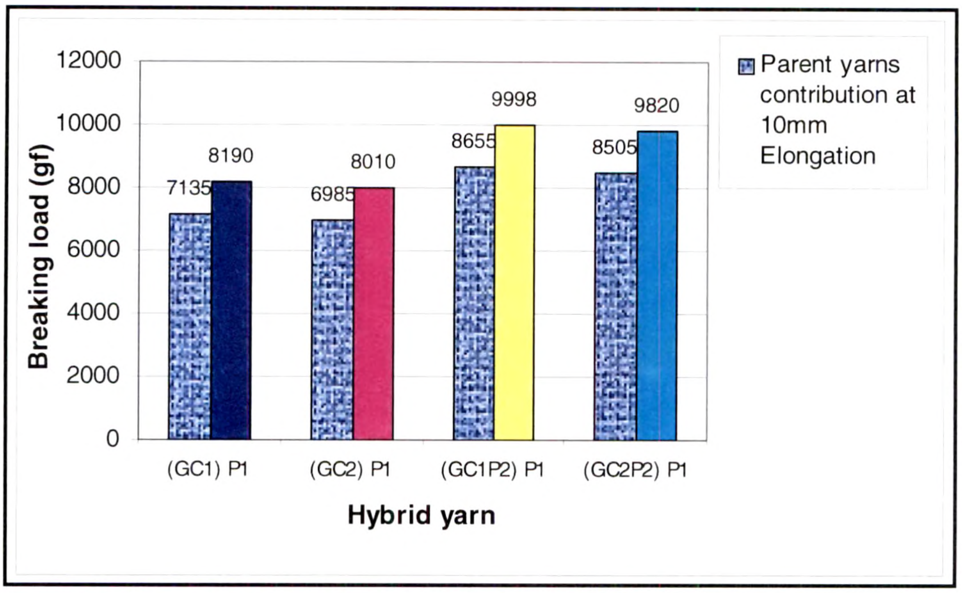

Fig. 4.16 (d) Contribution of parent yarn in breaking load of conductive hybrid yarn at 10mm elongation

Table 4.5 Contribution of Parent Yarn Strength in Conductive Hybrid Yarn at 10 mm Elongation of Component Yarns

Conductive hybrid yarn	**Load (gf)**		**% increase in strength of conductive hybrid yarn**
	Parent yarns contribution at 10mm elongation	**Conductive hybrid yarn**	
$(GC_1)\ P_1$	7135	8190	14.78
$(GC_2)\ P_1$	6985	8010	14.67
$(GC_1P_2)\ P_1$	8655	9998	15.51
$(GC_2P_2)\ P_1$	8505	9820	15.46

This may be attributed to low elongation of the glass filaments. The contribution of the polypropylene yarn to the conductive hybrid yarn strength is low as the load value at 10 mm elongation is only about 1520 g.

c) Proportion of mass of parent yarn

The proportions of component yarns in the each type of hybrid yarn have been measured by separation and weighing method. These proportions can significantly influence the conductive characteristics of laminates. The %

proportions of various material types in the resultant hybrid yarn have been shown in Table 4.6.

Table 4.6 Mass Proportion (%) of Component Yarns in Various Hybrid Yarn

	Type of hybrid yarns			
Component yarns	**(GC_1) P_1**	**(GC_2) P_1**	**(GC_1P_2) P_1**	**(GC_2P_2) P_1**
Glass	43	52	32	37
Copper	29	17	23	12
Polypropylene P_1	28	31	22	24
Polypropylene P_2	-	-	23	27
Total	100	100	100	100

Among the four hybrid yarns, prepared using glass and copper in the core contribution of glass in terms of weight is almost 50% and polypropylene approx 30%. As in other two sample polypropylene content 50% due to introducing 1000 denier polypropylene filament in core(Fig. 4.17). But in terms of strength no significant change as discussed in previous section. As content of polypropylene increases, the laminates are more plasticized .The distribution of this polypropylene inside lamination improves, which can be seen from SEM studies given in next section.

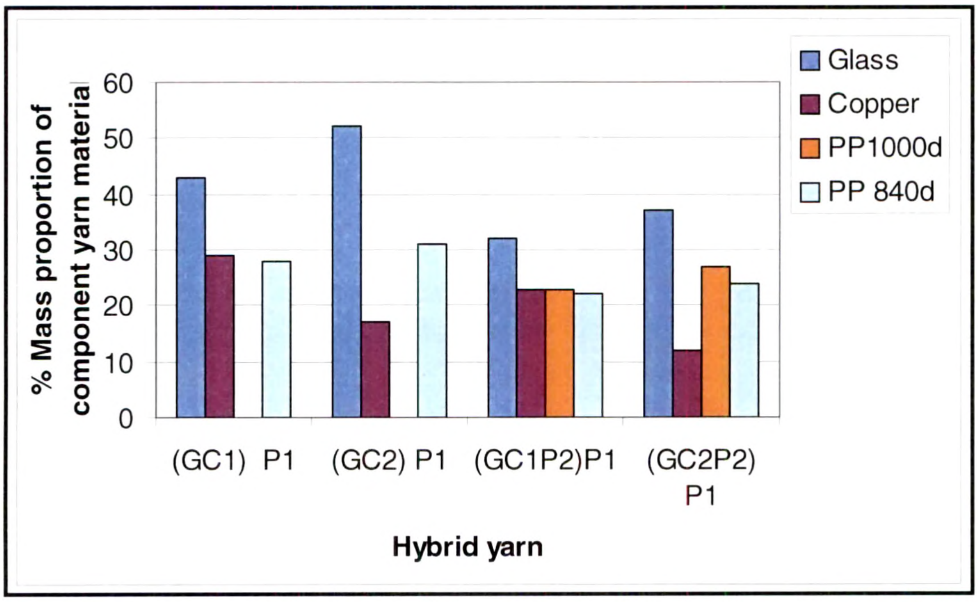

Fig. 4.17 Percentage contribution of component yarn in conductive hybrid yarn

4.4.2 Conductive Hybrid Yarn Fabric Properties

The Fabric Thickness and Courses/inch & Wales/Inch of the Composite fabric is discussed in Table 4.7.The fabric Structure and compactness depends on diameter of yarn and Number of Courses/inch & Wales/Inch in knitted fabric.

a) Fabric Thickness

Table 4.7 Fabric Thickness

Sample	Fabric Thickness (mm)	Courses/inch	Wales/inch
F_1 (GC_1) P_1	1.36	17	8
F_2 (GC_2) P_1	1.24	17	8
F_3 (GC_1P_2) P_1	1.76	16	7
F_4 (GC_2P_2) P_1	1.71	16	7

The fabric thickness of the conductive hybrid yarn given in the table above is of around 1.5mm and it can be observed that the fabric having polypropylene in the core has high thickness compared to fabrics without polypropylene in the core. Also, the fabrics of 40Swg having high thickness compared to 44Swg.

b) Courses/inch and Wales/inch

The Courses/inch and Wales/inch of the hybrid yarn fabrics given in the Table above is in range of around 16-17 and 7-8 respectively. It can be observes that the fabric having polypropylene in the core has low courses/inch and wales/inch compared to fabrics without polypropylene in the core.

4.4.3 Laminate

a) Tensile strength and Flexural rigidity (N/mm^2)

The tensile strength and flexural rigidity of the laminates were obtained on Universal Testing Machine. Due to the small quantity of the laminate and the difficulty associated with cutting of the samples, only five specimens of each type of laminate have been tested and the avarage values are given in Table 4.8. The Fig. 4.18 show that there is no significant change in tensile strength and flexural rigidity of laminates. The main reason for it is no change in glass content, which is responsible for laminate strength and flexibility.

Table 4.8 Tensile Strength and Flexural Rigidity

Laminates	Tensile strength (N/mm^2)	Flexural rigidity (N/mm^2)
L_1 (GC1) P1	2.9	73
L_2 (GC2) P1	2.8	72
L_3 (GC1P2) P1	2.95	75
L_4 (GC2P2) P1	2.85	74

b) Dielectric Strength (KV/mm)

Dielectric Strength is the measure of the maximum voltage a material can withstand without conducting electricity through the thickness of material. The insulating and conductive characteristics of material depend on its dielectric strength. Higher the values better is the insulation. The test results vary with thickness of material, rate of voltage, test duration and temperature. Table 4.9 show the value of dielectric strength of different thermoplastic laminates incorporating copper wire. Various specimens of same thickness of 2.5 mm have been made and evaluated for dielectric strength at uniform test conditions.

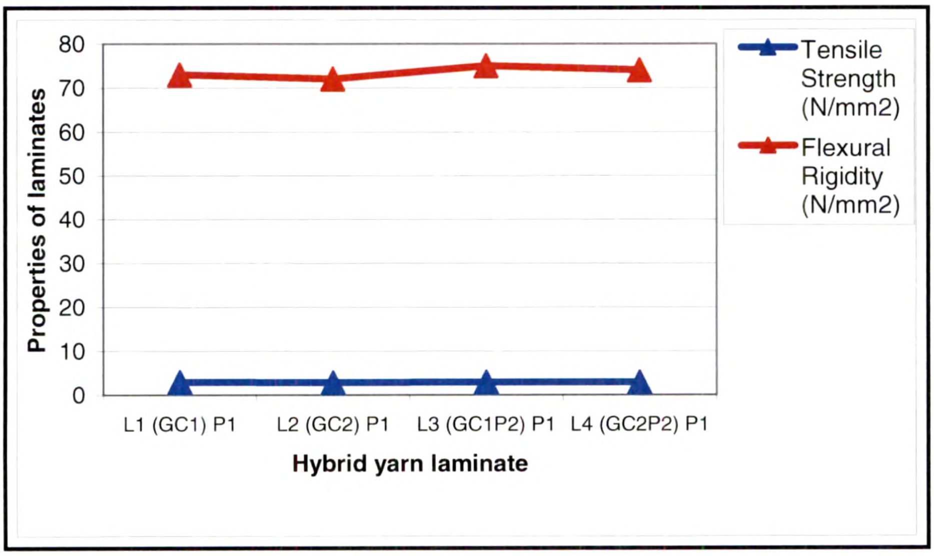

Fig. 4.18 Tensile strength and Flexural rigidity of hybrid yarn laminates

Table 4.9 Dielectric Strength of Various Laminates

Laminates	Breakdown voltage (KV)	Laminate thickness (mm)	Dielectric strength (KV/mm)
L_1 (GC1) P1	0.450	2.5	0.18
L_2 (GC2) P1	0.400	2.5	0.16
L_3 (GC1P2) P1	0.450	2.5	0.18
L_4 (GC2P2) P1	0.400	2.5	0.16

The dielectric strength of these laminates has been measured using method explained in section 4.3. It has been found that test samples got punctured low voltage range of 400v-450V, which show that these materials are good conductors. The laminate prepared with 40Swg shows little higher value as compared to 44Swg laminates samples(Fig. 4.19). These test results shows that the laminates prepared are conductive thermoplastic material.

c) Resistivity (Ohm)

The Surface resistance is the resistance determined by using specified electrodes placed on the surface of the material and surface resistivity is the resistance measured between opposite edges of a material. The Surface resistivity is independent of electrode dimensions and is calculated by multiplying the measured surface resistance by appropriate factors. The test has been carried out using method described in section 4.3 and results are tabulated in Table 4.10.

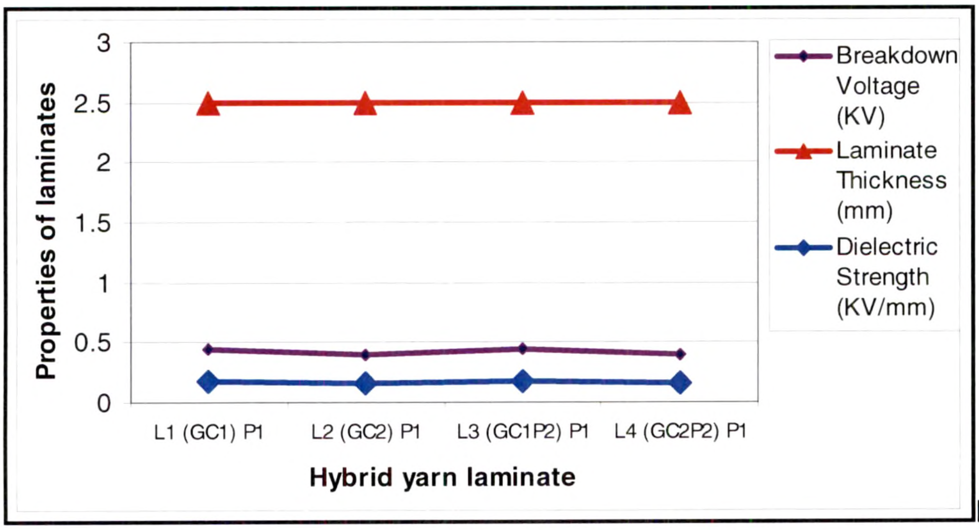

Fig. 4.19 Dielectric strength of laminates

The typical value of surface resistivity of various laminates have been found in range of 2.5 x 10^{12} to 4 x 10^{12} ohm/sq. In case of laminates with 40Swg (copper content: 29%), the surface resistivity values are higher than that of laminates with the 44Swg (copper content: 17%). Whereas with addition of polypropylene in the core, the surface resistivity values increases for both 40Swg ($L_3(GC_1P_2)P_1$: 23%) and 44Swg ($L_4(GC_2P_2)$ P_1: 12%). This indicates that the surface resistivity is affected not only by proportion of conductive material but also by the composite structure of the material (Fig. 4.20).

Table 4.10 Resistivity of Various Laminates

Laminates	Surface resistivity (ohm)	Volume resistivity (ohm – cm)
L_1 (GC1) P1	3 .0 X 10^{12}	5.0 X 10^{12}
L_2 (GC2) P1	2.5 X 10^{12}	4.5 X 10^{12}
L_3 (GC1P2) P1	4.0 X 10^{12}	6.0 X 10^{12}
L_4 (GC2P2) P1	3.5 X 10^{12}	5.5 X 10^{12}

Volume resistivity is a measurement of the resistance to the conduction of electricity provided by a unit volume of material. It is also described as the ratio of the voltage applied to one face of the material to the voltage existing on the opposite face of the cube. Higher the value indicates the greater insulation.

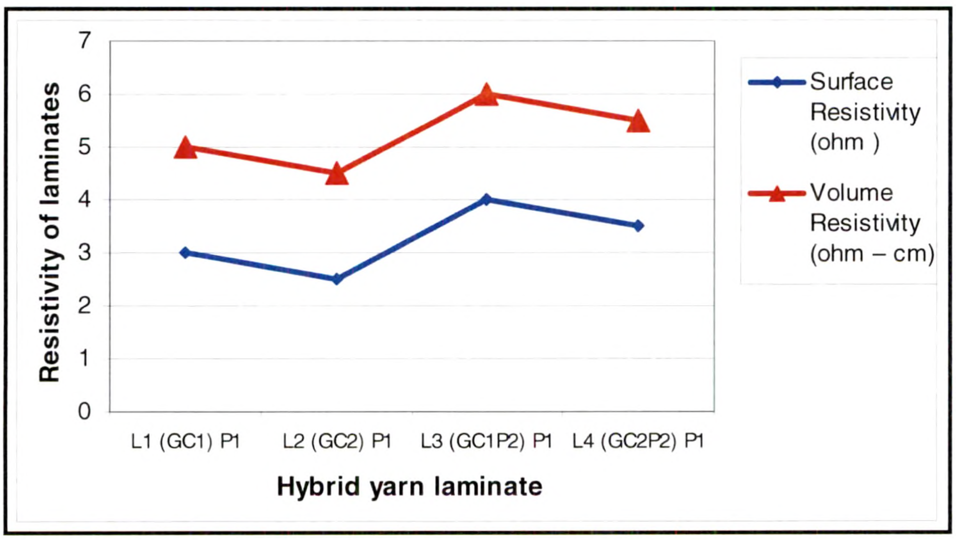

Fig. 4.20 Resistivity of laminates (x10^{12})

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The typical value of Volume resistivity is listed in Table 4.10. Volume resistivity of all these samples has been found in the range of 10^{12},which show the better insulating effectiveness. Increase in Polypropylene content increases value of insulating effectiveness. Hence, material is conductive with good insulating characteristics.

4.5 SEM OF CONDUCTIVE HYBRID YARN AND LAMINATES

The Scanning Electron Micrograph of the yarn cross-section and laminates has been studied to know the distribution of glass and polypropylene. Fig. 4.21(a) shows the details of cross section of hybrid conductive yarn sample [(GC_2P_2) P_1] at 75x and 200x magnification.

The sectional the glass is of cylindrical shape, polypropylene is of nearly oval shape and copper is in the shiny circular shape can be clearly distinguish. Due to the method of mounting the yarn on a flat plate and fixing it by a aluminum foil and subsequent cutting of the yarn, the cross section becomes flat. The side-by-side arrangement of the glass, polypropylene and the copper wire are clearly seen in Fig. 4.21(a).

Fig. 4.21 (b) shows the laminates cross sectional view of specimen L_2(GC_2) P_1 and L_4 (GC_2P_2) P_1 respectively. In laminate (GC_2) P_1 shows the even distribution of copper wire inside the body of laminate. Similarly in laminate L_4 (GC_2P_2) P_1 shows the homogeneous mixture of polypropylene matrix and glass filaments, with copper wire has embedded.

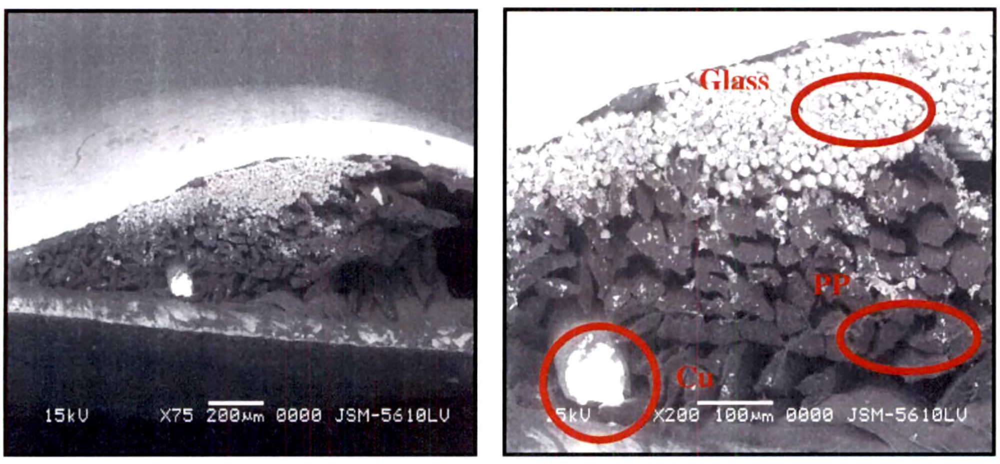

Fig. 4.21(a) Hybrid conductive yarn (GC_2P_2) P_1

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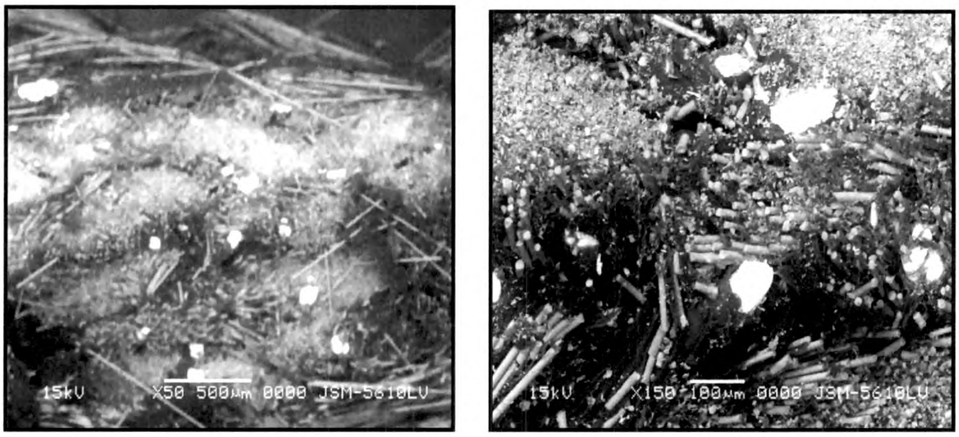
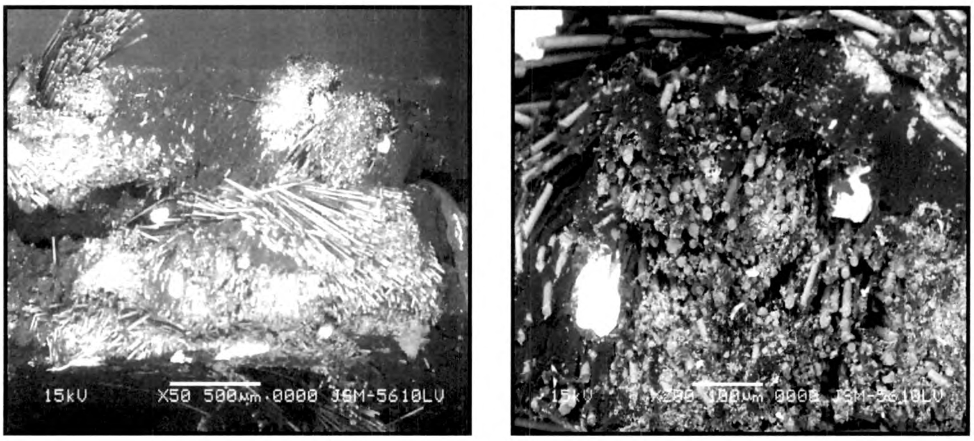


$L_2(GC_2)$ P_1



L_4 (GC_2P_2) P_1

Fig. 4.21 (b) SEM of hybrid yarns laminate

4.6 CONCLUSION

During application based studies on conductive hybrid yarns for thermoplastic composites, following the conclusions are drawn are:

1. Comparison of strength and elongation of the conductive hybrid yarns with the component yarns shows that
   - Strengths of the conductive hybrid yarns are about 15% higher than the cumulative contribution of the components at 10mm elongation.
   - Elongations of the conductive hybrid yarns are comparatively low due to the lower elongation of the glass filaments.
2. Tensile strength and Flexural rigidity of all the laminates types are obtained in close range values.
3. Dielectric strength of the laminates is in the range of 0.16 -0.18 KV/mm, which indicates that the composite materials are conductive in nature. The

values are higher for laminates with copper wire of 40 gauge as compared to that of laminates made using copper wire of 44 gauge. Also, Dielectric strength is not affected by the addition of polypropylene in the core.

4. The typical values of Surface resistivity and Volume resistivity of the samples have been obtained in the range of 2.5×10^{12} to 4×10^{12} ohm and 4.5×10^{12} to 6×10^{12} ohm-cm respectively, which indicates that the materials have better insulating effectiveness on the surface. Increase in polypropylene content increases the value of insulting effectiveness.
5. The low values of Dielectric strengths and high values of Surface and Volume resistivity indicate that the composite materials are of conductive with good insulating characteristics.