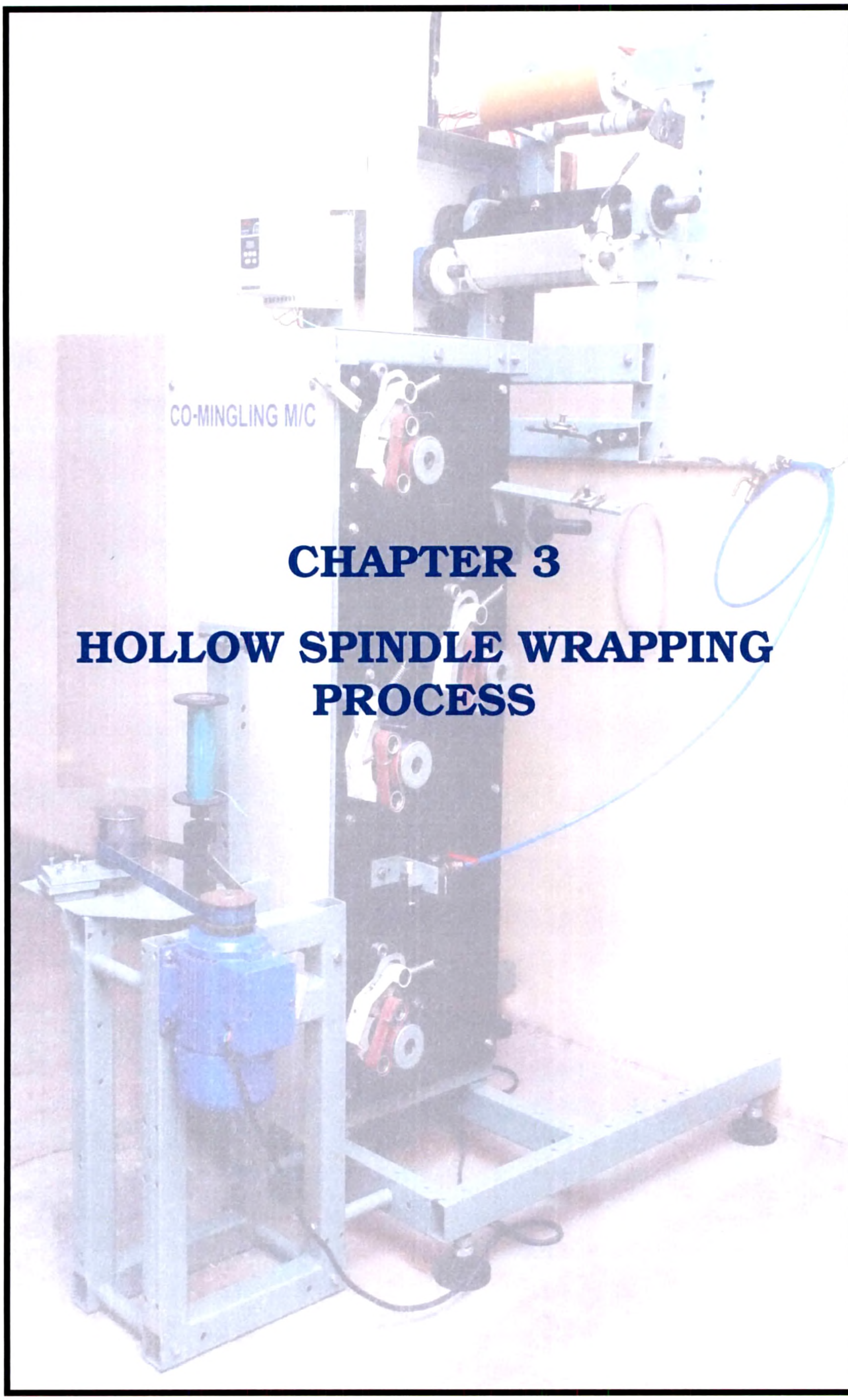
CHAPTER 3

HOLLOW SPINDLE WRAPPING PROCESS



CHAPTER 3 HOLLOW SPINDLE WRAPPING PROCESS

Various Characteristices of Hollow Spindle Hybrid Yarns

3.1 INTRODUCTION

Hollow spindle wrapping technique is mainly used to produce zari yarns, elstomeric yarns and such other cover yarns in which the core component mainly decides tensile perfomance of yarn and sheath component covering the core gives the asthetic value to the yarn. This process is also termed as covering process. Certain type of hybrid yarns can be produced by incorporating matrix and reinforce material using the hollow spindle wrapping technique. The hybrid yarns for industrial applications are mainly produced by incorporating thermoplstic yarn with reinforce material like glass and carbon. Certain conductive material can be incorporated with hybrid yarn for certain protection or shielding applications. This type of hybrid yarn improves weavability as well as knitting perfomance as compared to direct use of glass or carbon yarns for fabric formation.

In the present study, a hollow spindle wrapping machine has been fabricated for making the hybrid yarn by covering the polyester or polypropylene filament over glass or carbon filament core. The various types of hybrid yarns have been manufactured using glass/polyester, carbon/polyester and glass/ polypropylene. The details of hollow spindle wrapping machine and the effect of material and processing parameters on characteristics of hybrid yarn have been studied.

3.2 OBJECTIVE

The speciality hybrid yarns consisting of reinforcing and matrix fibres are mainly used for the formation of continuous filament reinforced composite. In many such applications of the thermoplastic composites, the glass filaments are used as reinforcing element for the polypropylene or polyester matrix. The properties of such thermoplastic composites can be mainly influenced by the arrangement of reinforcing filament and the homogenous distribution of filaments in the hybrid yarn. The hybrid yarns produced by different manufacturing techniques give different yarn appearance and yarn structure. In case of hollow spindle wrapping method, the thermoplastic yarn remains on the hybrid yarn surface, hence when the heat is applied to preforms made out of this yarn, the thermoplastic material melts and binds with the glass filaments and converts into composite. In this process the mass transfer distance of matrix is reduced but the homogeneity of polymer distribution is poor. On other hand the hybrid yarns made by mingling technology give better homogeneity in the composite.

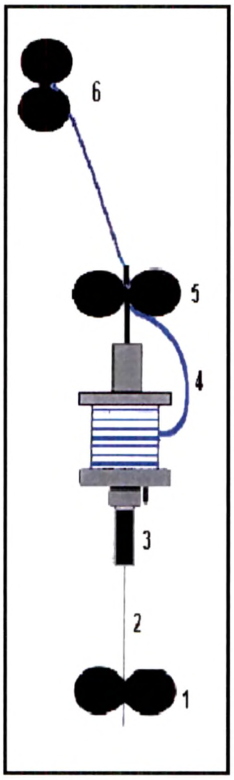
The main objective of this study is to understand hollow spindle wrapping process to produce hybrid yarn and modify the machine to produce various hybrid yarns viz. glass/polyester, carbon/polyester and glass/polypropylene, and to study the effects of materials and processing parameters on the characteristics of these wrapped hybrid yarns.

3.3 EXPERIMENTAL PROCEDURE

3.3.1 Principle of Hollow Spindle Wrapping Technique

The hollow spindle wrapping technique is slightly different from hollow spindle spinning technique. In case of the hollow spindle wrapping technique, the core yarn is directly fed from supply package without tension through hollow spindle. The spindle rotates with filament bobbin at pre determined speed. The filament is drawn off the upper end of the bobbin and passed through the nip of nip roller forming core-sheath type wrapped yarn. The emerging yarn is wound into a large take-up package. Some hollow spindle machines also have two such spindles each one rotating in opposing direction to give double-wrap yarns; but the single-wrap system is the most common.

A typical wrap yarn, therefore, consists of a parallel assembly of core yarn helically wrapped with yarn or filament. When such a yarn is extended, the axial force of the wrapper yarn compresses the filament in the core by inward radial pressure, leading to high frictional forces and providing yarn strength.



1. Feed roller
2. Core yarn
3. Hollow spindle
4. Sheath yarn
5. Nip roller
6. Winding unit

Fig. 3.1 Principle of hollow spindle wrapping process

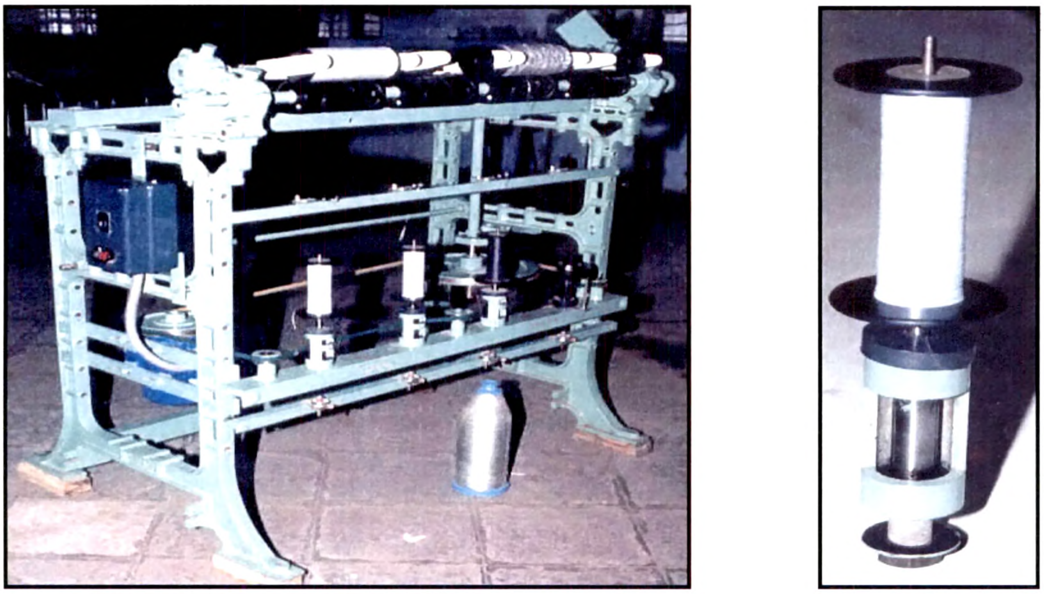
The principle of hollow spindle wrapping technique is shown in Fig. 3.1 in which core yarn passes through the bottom of hollow spindle and the double flange bobbin with wrap yarn is mounted on the spindle. As the spindle rotates, the filament is unwound from the double flange bobbin and binds the core yarn by spiral wraps.The required number of wraps in the yarn can be obtained by controlling the spindle speed and yarn take up speed.

3.3.2 Fabrication of Hollow Spindle Wrapping Machine

A laboratory scale hollow spindle wrapping machine has been fabricated at Textile and Allian Industrial Research Organization (TAIRO), Vadodara. The machine basically consists of 4 hollow spindle units driven by tangential belt as shown in Fig. 3.2(a). The hollow spindle assembly as shown in Fig. 3.2(b) has been obtained from Sapru Industrial Works, Surat. The winding unit is mounted at the top and the drive is transmitted to winding unit by a train of gears comprising of a change gear to set the amount of wrap in the yarn (Fig. 3.3). Various specifications of the machine are given in Table 3.1.

Table 3.1 Technical Specifications of Hollow Spindle Wrapping Machine

1	Motor speed	1440 rpm
2	Motor pully diameter	152.5 mm
3	Spindle wharve diameter	22.5 mm
4	Spindle speed	9760 rpm
5	Vertical shaft pulley diameter	305 mm
6	Type of worm	4 fold
7	Worm wheel	36 T
8	Worm shaft speed	80 rpm



(a) Feed of parent yarns and winding of hybrid yarns

(b) Hollow spindle assembly

Fig. 3.2. Hollow spindle wrapping machine

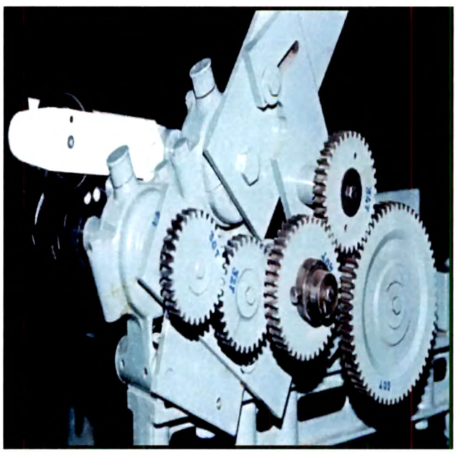


Fig. 3.3 Train of gears with wrap change gear

3.3.3 Wrap Level (Twist Level) of Hybrid Yarn

In hollow spindle wrapping process, the characteristics of hybrid yarns depend on material and processing parameters. The details of drive to the spindle and winding unit of hollow spindle wrapping machine is shown in Fig. 3.4. The number of wraps in the yarn depends on spindle speed and yarn delivery rate. To change the wrap level, the combination of gear A, B, C, D need to be changed. The machine is equipped with 3 phase DC motor(1440 rpm), to drive all the spindles by tangential belt arrangment. From the specifications of the machine, the spindle speed can be calculated as follows:

$$\textbf{Spindle speed (rpm)} = \frac{\text{Motor speed in rpm} \times \text{Diameter of motor pulley}}{\text{Diameter of spindle wharves}}$$

=1440 x 152.5 / 22.5

= 9760

As per the gearing diagram in Fig. 3.4, gear A = Twist constant change wheel and gear B = Twist change wheel.The various delivery speeds, twist constant and twist levels may be obtained as under for different combinations of gear A and gear B.

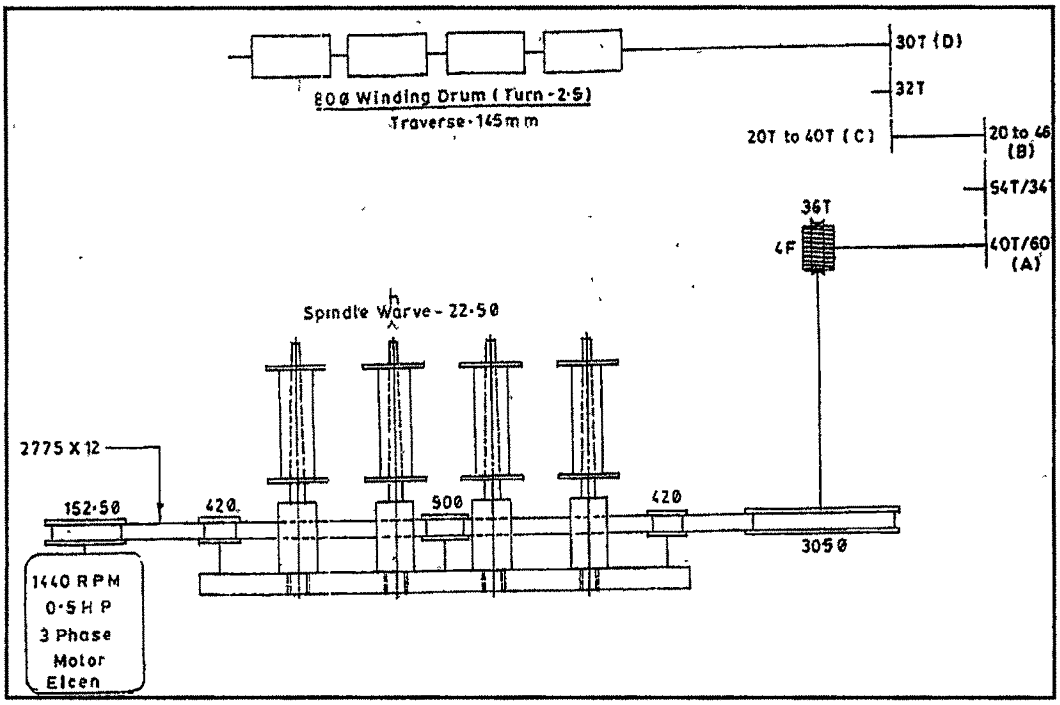


Fig 3.4 Schematic diagram showing detail of drive to spindle and winding unit

- **Delivery speed**

Delivery roller 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

Delivery roller speed with A = 60T and B = 46T

= 1440 x (152.5 / 305) x (4 / 36) x (60 / 46) x (20/30) x 3.14 x 0.08

= 17.47 m/min

Delivery roller speed with A = 40T and B = 20T

= 1440 x (152.5 / 305) x (4 / 36) x (40 / 20) x (20/30) x 3.14 x 0.08

= 26.79 m/min

Delivery roller speed with A = 40T and B = 46T

= 1440 x (152.5 / 305) x (4 / 36) x (40 / 46) x (20/30) x 3.14 x 0.08

= 11.64 m/min

- **Twist constant**

For one revolution of delivery roller, number of revolutions made by spindle with A = 60T and B = 20T

$$= \frac{1\times(30/20)\times(20/60)\times(36/4)\times(305/152.5)}{3.14\times0.08}$$

$$= 242.8$$

Twist constant

$$= \frac{1\times(30/20)\times(1/60)\times(36/4)\times(305/152.5)}{3.14\times0.08}$$

$$= 12.14$$

For one revolution of delivery roller, number of revolutions made by spindle with A = 40T and B = 20T

$$= \frac{1\times(30/20)\times(20/40)\times(36/4)\times(305/152.5)}{3.14\times0.08}$$

$$= 364.2$$

Twist constant

$$= \frac{1\times(30/20)\times(1/40)\times(36/4)\times(305/152.5)}{3.14\times0.08}$$

$$= 18.21$$

Table 3.2 Wrap Level of Yarn Using Various Combination of Gears

Number of Gear Teeth (T)				**Drum Speed** (m/min)	**Wrap Level** (TPM)
A	**B**	**C**	**D**		
60	20	46	30	92.44	105
60	22	36	30	65.77	148
60	30	36	30	48.23	202
60	32	30	30	37.58	259
60	30	24	30	32.15	303
60	32	22	30	27.63	353
40	30	24	30	24.63	396
40	40	30	30	21.50	454
40	40	28	30	18.68	522
40	36	24	30	17.58	552
40	36	22	30	16.37	596
40	36	20	30	14.87	656
40	40	20	30	13.46	725

- **TPM (Turn per meter or wrap per meter)**

a) With A = 60T, B = 20T and TCW = 46

TPM = Twist constant x Twist change wheel (TCW)

= 12.14 x 46

= 558.44

With A = 60T, B = 20T and TCW = 20

TPM = Twist constant x Twist change wheel (TCW)

= 12.14 x 20

= 242.8

The twist level can be obtained in the range of 242.8 to 558.44 TPM.

b) With A = 40T, B = 20T and TCW = 46

TPM = Twist constant x Twist change wheel (TCW)

= 18.21 x 46

= 837.66

With A = 40T, B = 20T and TCW = 20

TPM = Twist constant x Twist change wheel (TCW)

= 18.21 x 20

= 364.2

The twist level can be obtained in the range of 364.2 to 837.66 TPM.

3.3.4 Preparation of Hybrid Yarns

Various types of hybrid yarns have been prepared using the hollow spindle wrapping process on the machine, which has been fabricated for this purpose. These yarns have been made from four types of parent filament yarns viz. glass, polyester, carbon and polypropylene(Fig.3.5).The specifications of various types of these yarns have been given in Table 3.3.

Totel of eleven different yarns viz. glass and polyester yarns each of four different linear densities, polypropylene yarns each of two different linear densities and one carbon yarn have been used to prepare different types of hybrid yarn. The glass and carbon are used in the core as reinforcing element, whereas polyester and polypropylene are used in sheath as matrix materials. The core component unwound from the bottom, passes through the centre of hollow spindle and moves upward to the take-up device.

Table 3.3 Specifications Of Various Types of Parent Yarns Used for Preparing Hybrid Yarns

Sr. No.	Type of yarn	Code	Linear density (Denier)	Number of filament	Density (g/cm^3)	Tenacity (cN/tex)	Extension (%)	Friction co-efficient (M)
1	Glass	G_1	684	3600	2 54	43 28	1.56	0 507
		G_2	1395	3600	2.54	44.01	2.20	0 567
		G_3	2700	3600	2 54	25.2	1 03	0 594
		G_4	5400	3600	2.54	17.3	1 20	0.683
2	Polyester	PT_1	220	72	1 36	22.28	23	0 608
		PT_2	330	108	1.36	20.76	25	0 608
		PT_3	440	144	1 36	18 66	22	0.608
		PT_4	550	180	1.36	20.70	26	0 608
3	Carbon	C	1602	3000	1.7	46 06	0 59	0 406
4	Polypropylene	PP_1	840	144	0 90	26.55	26.55	0 743
		PP_2	1000	144	0.90	47.34	47.34	0.743

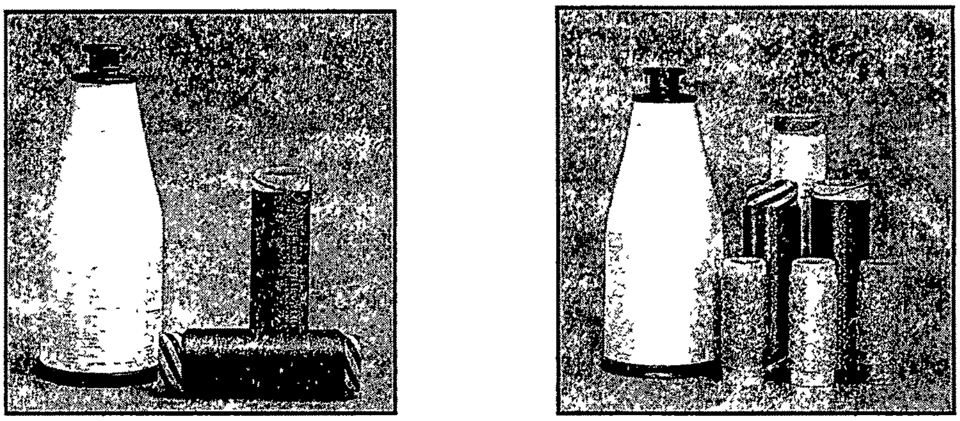


Fig 3.5 Raw material and sample prepared

Table 3.4 Various Hybrid Yarns Made by Hollow Spindle Wrapping Process

Sr. No.	Type of hybrid yarn	Element of hybrid yarn		Linear density (tex)		Twist level (TPM)	Sample code
		Core	Sheath	Core	Sheath		
1	Glass/PET	Glass	Polyester	75	24.44	300	G_1PT
				150			G_2PT
				300			G_3PT
				600			G_4PT
2	Glass/PET	Glass	Polyester	75	24.44	400	G_1PT*
				150			G_2PT*
				300			G_3PT*
				600			G_4PT*
3	Glass/PET	Glass	Polyester	150	24.44	300	GPT_1
					36.66		GPT_2
					48 88		GPT_3
					61.11		GPT_4
4	Carbon/PET	Carbon	Polyester	178	24.44	300	CPT_1
					36.66		CPT_2
					48.88		CPT_3
					61.11		CPT_4
5	Glass/PP	Glass	Polypropylene	150	93.33	300	GPP_1
					111.11		GPP_2

In case of glass/polyester hybrid yarn, glass is in the core for which constant tension is required on the yarn to avoid bending. Also the surface of each part should be as smooth as possible to avoid breakages. Polyester is wrapped around glass due to rotation of hollow spindle bobbin.The twisting of polyester around glass depends on the setting of gears, to set wraps per meter.

The core yarn is covered by wrappping of sheath component by rotation of double flange bobbin mounted on the hollow spindle. The various hybrid yarns using core-sheath combination such a glass/polyester,carbon/polyester and glass/polypropylene have been made using twist level of 300 TPM. To study the effect of twist level on properties of hybrid yarns, glass/polyester yarns have also been made with higher twist of 400 TPM (Table 3.4).

3.3.5 Measurement of Hybrid Yarns Properties

Various characteristics of yarn such as yarn linear density, breaking load and extension at break have been measured for parent yarns and hybrid yarns using the standard test methods.

a) Linear Density

The linear density of yarn is measured in terms of denier. Denier is defined as the mass of material in grams of 9000-meter length. The yarn hank of 90 meter length is prepared at nominal reeling tension on wrap reel having circumference of one meter. The mass of hank is measured using electronic balance The specifications of electronic balance are as under:

- Model: AEL-40SM
- Capacity: 42 g
- Accuracy: 0.01 mg

In case of all hybrid yarns five specimens have been used to calculate the average linear density of yarn and expressed in denier and tex.

b) Yarn Tenacity

The mechanical properties are tested using Lloyds Tensile Tester, interfaced with computer(Fig. 3.6). The breaking load and elongation at break for different yarns have been measured on the machine at 300 mm gauge length and 300 mm/min cross head speed. The average value of breaking load of hybrid yarns have been used to calculate the yarn tenacity.

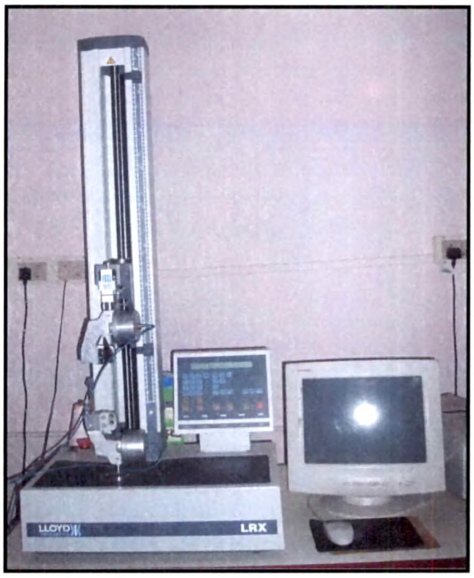


Fig 3.6 Lloyds Tensile Tester

The particulars of Lloyds Tensile Tester are as under:

- Model: LRX 2K5
- Maximum force: 5000N
- Over all force range: 0.5N-5000N
- Cross head speed range: 0.1-500 mm/min

3.4 RESULTS AND DISCUSSION

The various types of wrapped hybrid yarns composed of separate components in core and wrap component in sheath have been prepared using hollow spindle wrapping machine. The detailed specifications of parent yarns are given in Table 3.3. The hybrid yarn specifications are listed in Table 3.4 along with, code and the type of component in core and sheath. The various characteristics of hybrid yarns are listed in Table 3.5. The Effect of twist level, core/ wrap yarn denier and material type on characteristics of hybrid yarns have been studied.

3.4.1 Effect of Core Yarn Properties on Hybrid Yarn Properties

The hybrid yarns consisting of glass in core wrapped with polyester in sheath have been prepared with different glass linear density (Table 3.5, sample code G_1PT to G_4PT). The effect of core yarn linear density on glass/polyester hybrid yarns properties along with parent yarn are shown in Fig. 3.7(a)-Fig. 3.7 (e).

Table 3.5 Various Characteristics of Wrapped Hybrid Yarns

Sample code	Linear density (Tex)	Linear density (Denier)	Breaking load (kgf)	Tenacity (cN/tex)	Extension (%)
Glass/PET hybrid yarn with different core denier at 300 TPM					
G_1PT	176	1586	6.13	34.82	2.6
G_2PT	264	1610	8.61	48.13	2.54
G_3PT	326	2934	15.2	46.62	2 94
G_4PT	628	5654	24.7	39.31	3.58
Glass/PET hybrid yarn with different core denier at 400 TPM					
G_1PT^*	165	1487	7 01	42.42	3.51
G_2PT^*	252	2267	12.6	50 02	3 3
G_3PT^*	318	2858	15.7	49 44	3.41
G_4PT^*	612	5511	30 7	50.1	3.85
Glass/PET hybrid yarn with different wrap yarn denier					
GPT_1	264	1610	8 61	48 13	2.54
GPT_2	210	1890	8.56	40.76	3.7
GPT_3	217	1956	9.5	43.71	4.19
GPT_4	228	2049	9.94	43 66	4.06
Carbon/PET hybrid yarn with different wrap yarn denier					
CPT_1	218	1965	13.9	63.66	1.48
CPT_2	220	1979	13 7	62.30	1.45
CPT_3	259	2329	15.6	60.28	2.1
CPT_4	267	2404	16 1	60.27	1 92
Glass/PP hybrid yarn with different wrap yarn denier					
GPP_1	348	3127	8.09	23 28	3.57
GPP_2	399	3597	8 01	27.75	3.78

In case of hybrid yarn produced by wrapping process, the core component, mainly affects the final properties of yarn. The linear density of yarn depends upon core yarn linear density, wrapped yarn linear density and twist level (wraps per meter). It is clearly seen from Fig. 3.7(a) that the core yarn component significantly affects the hybrid yarn denier, with same wrap filament denier and constant twist per meter. The effects of twist level also influence the linear density of hybrid yarn marginally (Fig. 3.7(b)).

The glass filaments in core are contributing more than 80% of yarn strength. So, as glass linear density increases the breaking load of hybrid yarn increases (Fig. 3.7(c)). Hence, mass stress at break i.e. tenacity of hybrid yarn decreases with increase in linear density of core yarn (Fig. 3.7(d)).

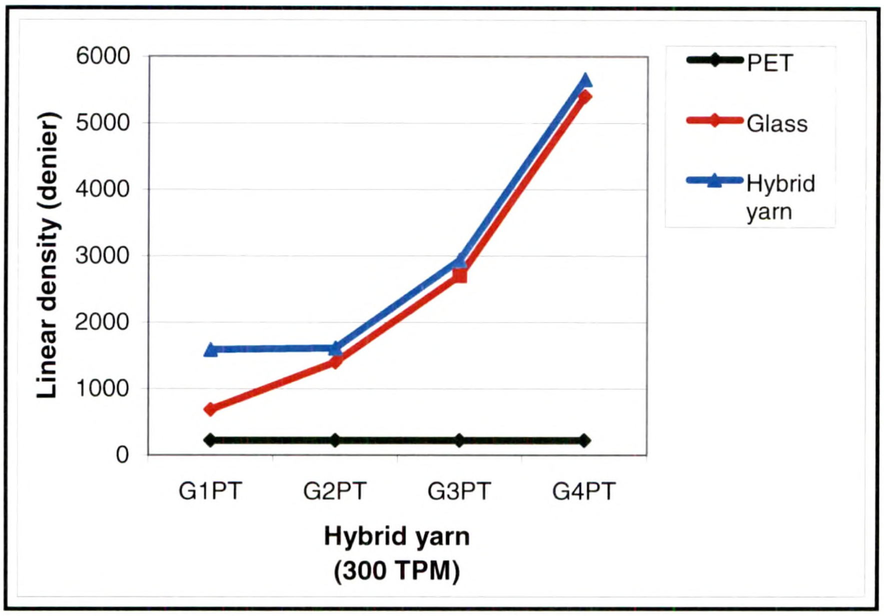


Fig 3.7 (a) Effect of linear density of core yarn on linear density of hybrid yarn

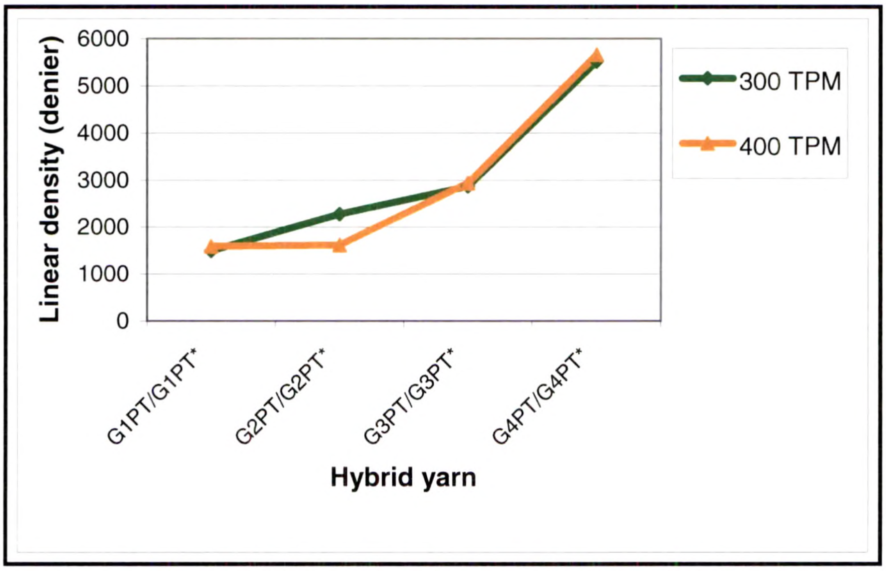


Fig 3.7 (b) Effect of twist level on linear density of hybrid yarn

Fig. 3.7(e) shows that the extension at break of the hybrid yarn is mainly influenced by the straight core component i.e. glass. The polyester filaments have higher value of extension as compared to that of glass but the hybrid yarn extension % is near to glass extension%.

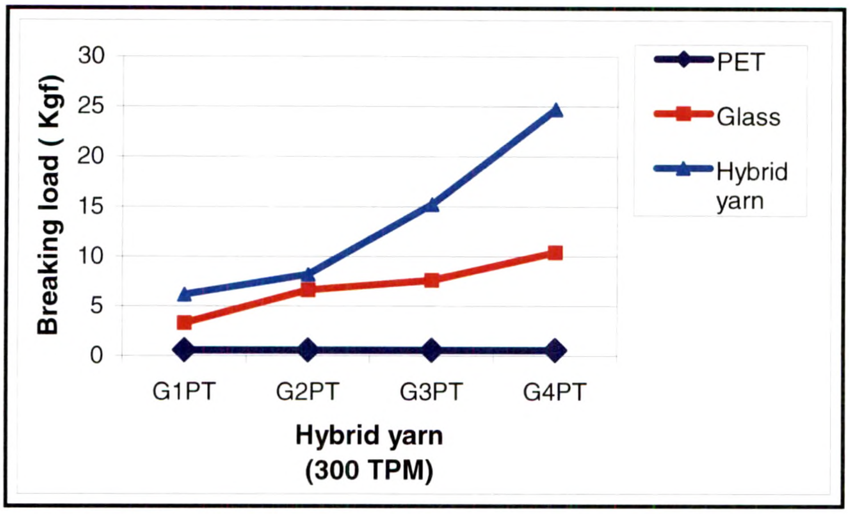


Fig 3.7(c) Effect of core yarn linear density on breaking load of hybrid yarn

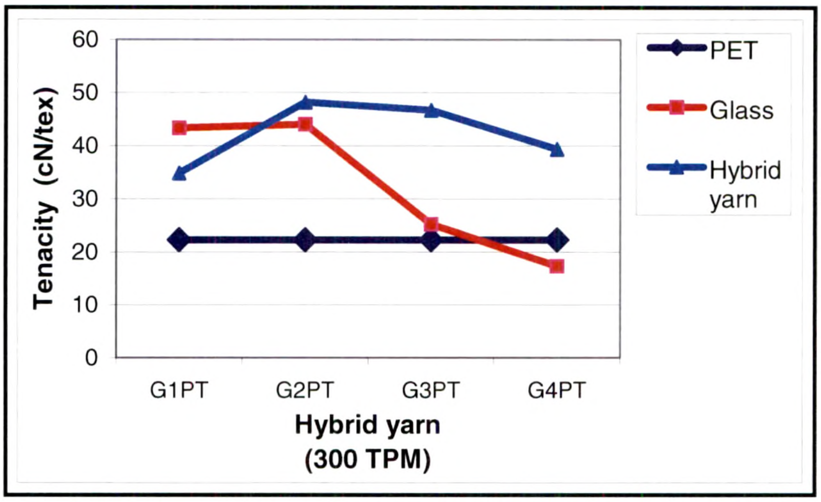


Fig 3.7(d) Effect of core yarn linear density on tenacity of hybrid yarn

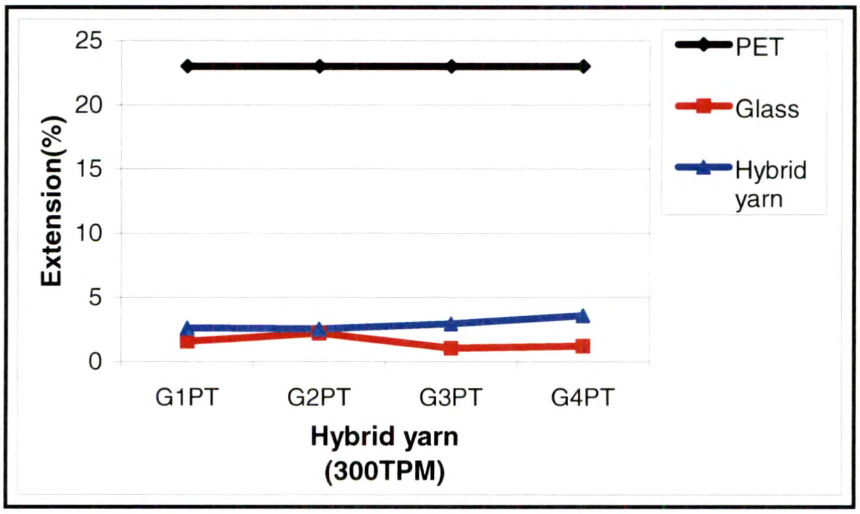


Fig 3.7 (e) Effect of core yarn linear density on extension of hybrid yarn

In consolidation process, for the hybrid yarns in preform stage, the polyester filaments would melt and glass filaments would provide strength to laminates. Hence, the core material selection and its properties in hybrid yarns, significantly contribute in deciding the final strength and the performance of composites.

3.4.2 Effect of Wrapped Yarn Properties on Hybrid Yarn Properties

The hybrid yarn consisting of glass in core and polyester in wrap, is prepared with different polyester linear density (Table 3.5, sample code GPT_1 to GPT_4). The effect of wrap yarn linear density on glass/polyester hybrid yarn properties along with parent yarn are shown in Fig. 3.8(a) to Fig. 3.8(d).

It can be clearly seen from Fig. 3.8(a) that for constant linear density of glass filament and TPM value, with increase in linear density of polyester, the hybrid yarn linear density increases marginally. Fig. 3.8(b) shows the comparison of breaking level of hybrid yarns when sheath yarn(PET) linear density is increased for same glass core. The glass filament in core mainly contributes in yarn strength but wrapped yarn also gives binding force to core yarn. As polyester linear density increases, the breaking load of hybrid yarn also increases. Hence, mass stress at break i.e. tenacity decreases with increase in linear density as shown in Fig.3.8(c). However it has been observed that there is no significant change in the breaking extension of hybrid yarn (Fig. 3.8(d)).

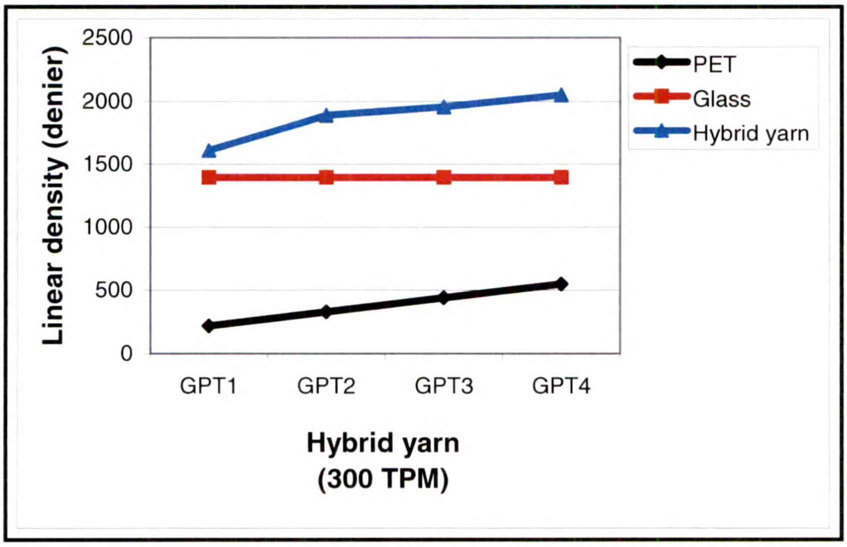


Fig 3.8 (a) Effect of wrap yarn linear density on linear density of hybrid yarn

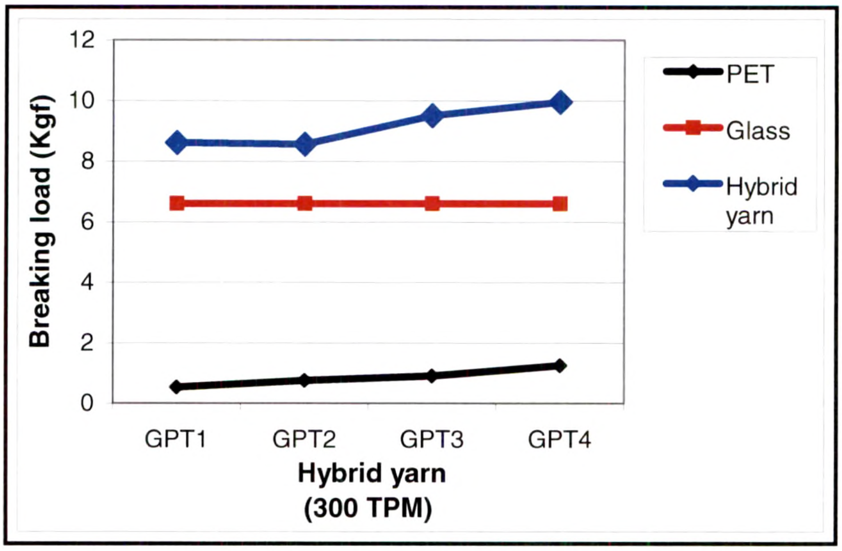


Fig. 3.8(b) Effect of wrap yarn linear density on breaking load of hybrid yarn

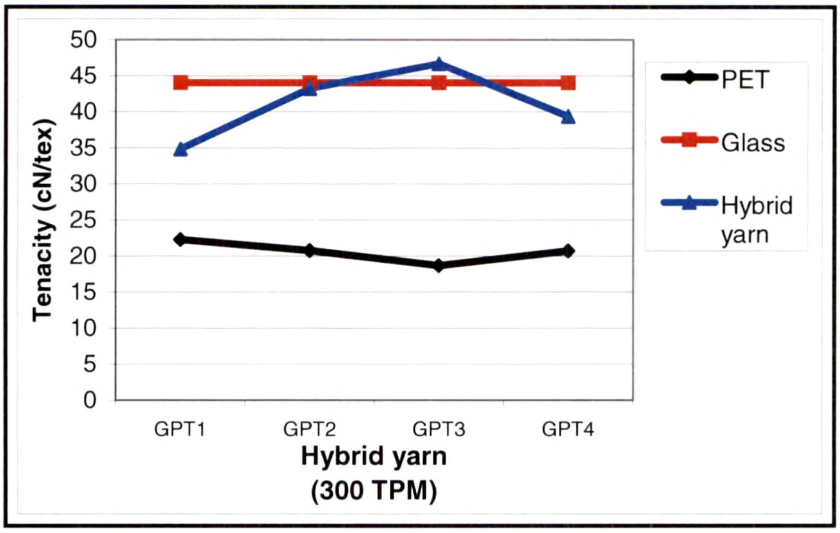


Fig. 3.8(c) Effect of wrap yarn linear density on tenacity of hybrid yarn

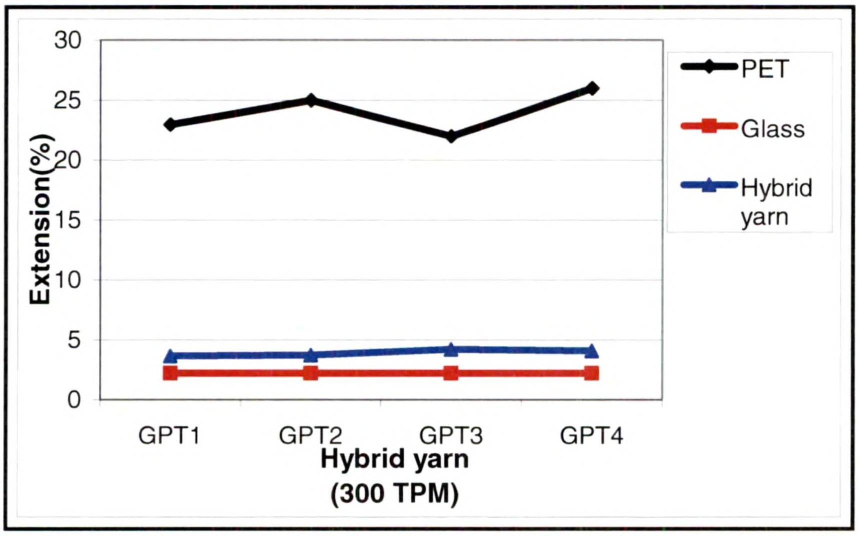


Fig. 3.8(d) Effect of wrap yarn linear density on extension of hybrid yarn

The distribution of thermoplastic component(PET) with matrix(Glass) in the hybrid yarn decides the performance of composites. Hence, wrapped yarn percentage and its distribution are important parameters to understand behaviour of thermoplastic composites.

3.4.3 Effect of Different Core Yarn Materials on Hybrid Yarn Properties

The hybrid yarns consist of glass or carbon filaments as the core material and polyester in wrap is prepared with different polyester linear densities(GPT_1 to GPT_4 and CPT_1 to CPT_4). The linear density of both the types of materials used as core has been selected in narrow range as glass-150 tex and carbon-178 tex.

The Breaking load, tenacity and extension of carbon/polyester and glass/polyester have been compared in Fig. 3.9(a), Fig. 3.9(b) and Fig. 3.9(c) respectively. Carbon/polyester yarn gives higher breaking load as compared to that of yarn made with glass core. The tenacity and extension of glass core hybrid yarn shows higher value compare to carbon core hybrid yarn.

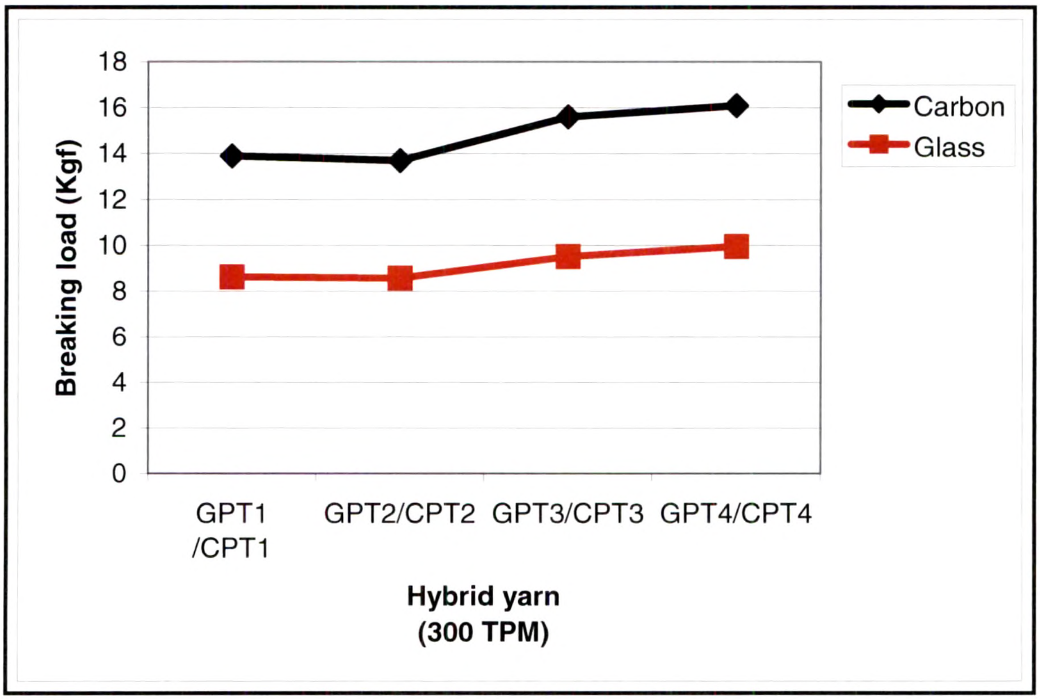


Fig 3.9 (a) Effect of core yarn material on breaking load of hybrid yarn

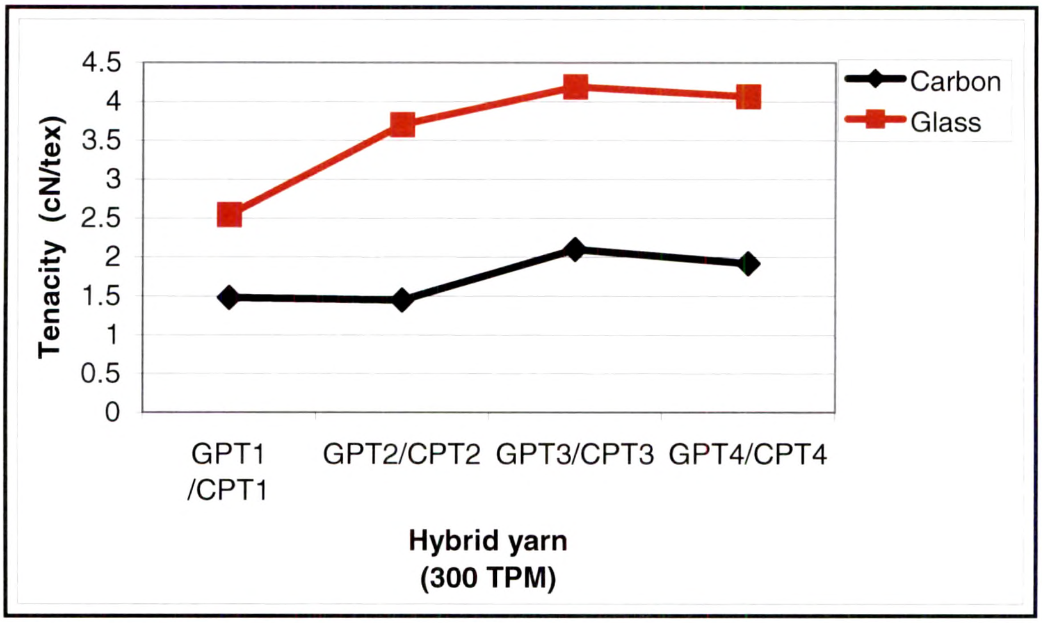


Fig 3.9 (b) Effect of core yarn materials on tenacity of hybrid yarn

Generally the selection of reinforced material is based on composite requirement. The carbon is used in applications, where conductive properties are required but carbon pose risk of accident, due to particles deposits on machine parts during process. In hollow spindle wrapping process it is possible to process carbon without much damage. Moreover due to wrapping of carbon with polyester yarn it is possible to use it for weaving.

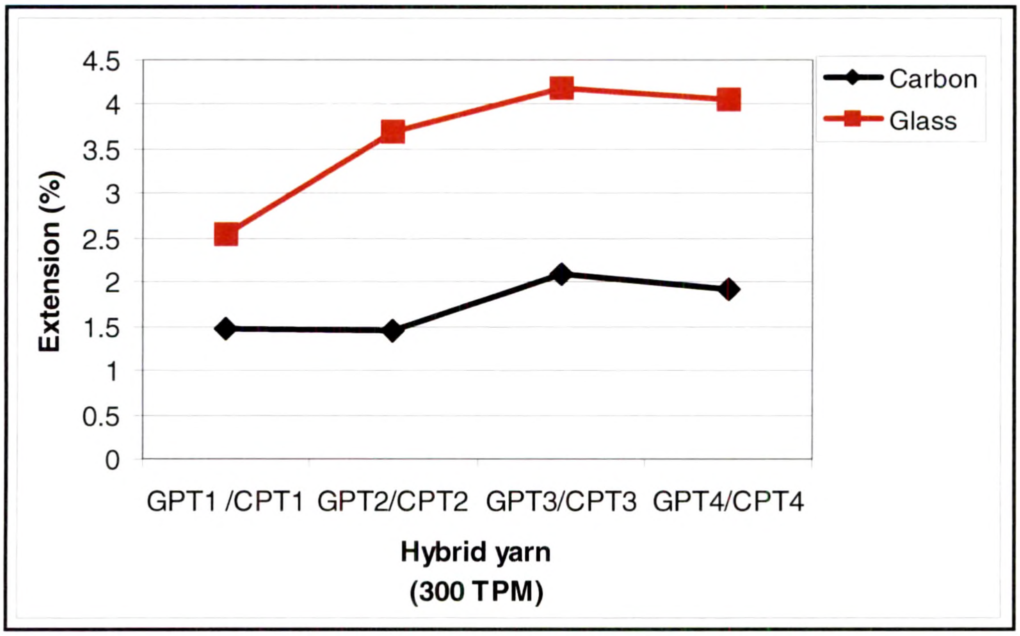


Fig 3.9(c) Effect of core yarn material on extension of hybrid yarn

The distribution of thermoplastic component(PET) with matrix(Glass or Carbon) in hybrid yarn decides the performance of composites. Hence the core material and wrap material in hybrid yarn have significant effect on properties and performance of final composites.

3.4.4 Effect of Twist Level on Hybrid Yarn Properties

In hollow spindle wrapping process the main processing parameter is twist level. The different twist levels are set by selecting a gear combination as shown in Table3.2. In case of hybrid yarn it was observed that low twist level (below 250 TPM) gives slippage of wrap yarn over core filament, where as higher twist level (above 450 TPM) gives stiff yarn with snarling tendency.

The various hybrid yarn samples of different linear density of glass in core with same polyester as wrap with 300 TPM and 400 TPM are prepared (see Table 3.4 for code G_1PT to G_4PT and G_1PT^* to G_4PT^*). The effect of twist level on breaking load, tenacity and extension % of hybrid yarn are shown in Fig.3.10. Higher wrap level gives more cover to core leading to compact yarn structure. Thus, with higher twist level, breaking load improves in all the yarns due to increase in binding force. Same effect is also seen in case of tenacity due to increase in the tensile strength. Extension at break also increases marginally for all these yarns.

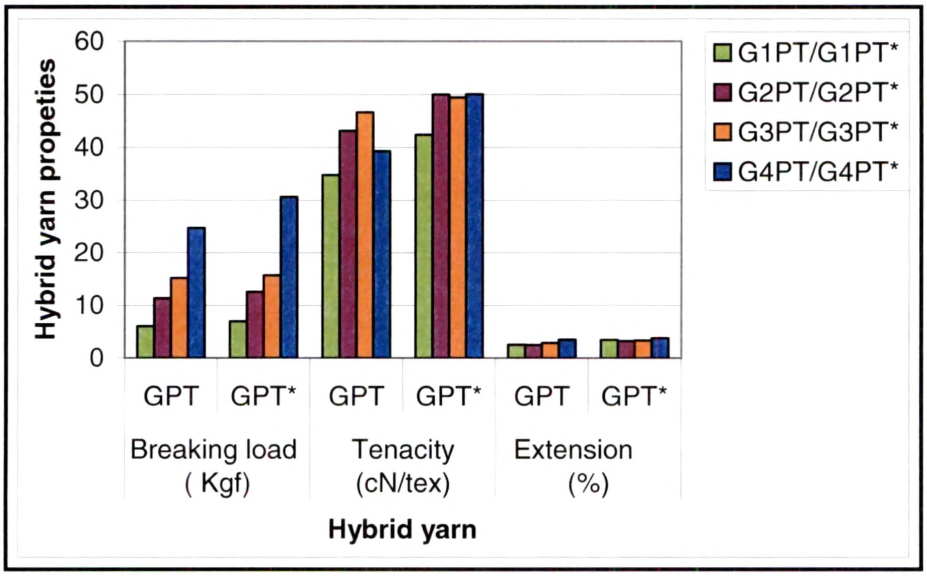


Fig. 3.10 Effect of twist level on hybrid yarn properties

As wrapped yarn percentage and its distribution are important parameters to understand behaviour of thermoplastic composites, higher number of wrap give better cover to core yarn, but homogenous mixing of thermoplastic filament can be improved by incorporating with glass filament in core.

3.4.5 Analysis of Hybrid Yarn Structure by Scanning Electron Micrograph

The structure of hybrid yarn produced by hollow spindle wrapping process has been analysed to study the mixing behaviour of hybrid yarn. Fig. 3.11(a) shows the cross sectional view of glass/polyester hybrid yarn. It clearly shows that core of yarn is comprises of glass filaments and polyester filaments are covering the glass. There is no mixing of glass and polyester filament in yarn. When this yarn is used in final composites, it shows improper distribution of matrix and reinforcing filament affecting mechanical properties of the composite.

Fig. 3.11(a) SEM of Glass/Polyester hybrid yarn

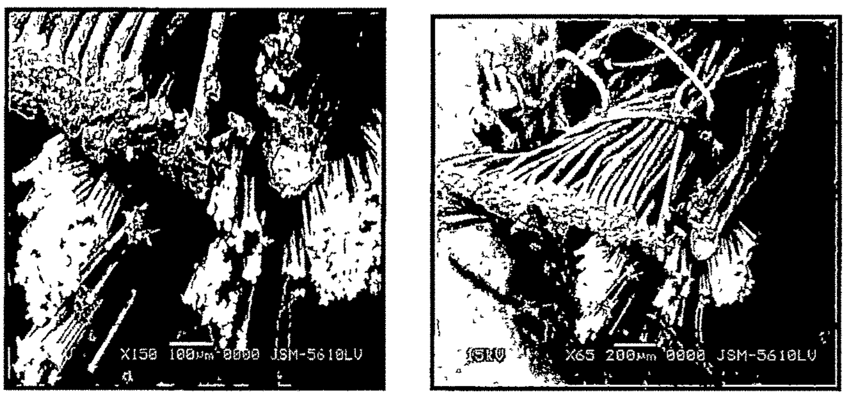


Fig.3.11 (b) SEM of Glass-Polypropylene / Polypropylene hybrid yarn

Fig. 3.11(b) shows cross sectional view of glass-polypropylene/polypropylene hybrid yarn. It is observed that by introducing the matrix material in core along with reinforced material, both yarns remain in cluster form in center of hybrid yarn; which improves distribution of matrix material within the yarn but not within glass.

3.5 CONCLUSIONS

Following conclusion can be derived from the study on hybrid yarns prepared by the hollow spindle wrapping process.

1. The hollow spindle wrapping process is used to produce hybrid yarn with reinforced core and matrix in sheath, where core component decides the performance and properties of final composite.
2. The hollow spindle machine fabricated is required for straight core yarn path with tension control to avoid breakage of glass filaments during the process.
3. The effect of core yarn linear density directly affects the mechanical properties of hybrid yarn and its performance during subsequent conversion process.
4. The different reinforcing materials in core give different mechanical properties. The selection of which depends on final functional requirements.
5. The twist level and wrap yarn linear density decides the percentage distribution of matrix material with respect to reinforced material in hybrid yarn.
6. It is easy to process carbon using this technique of producing hybrid yarn, which is easier to handle in subsequent process.