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Preparation and Evaluation of Polyester Hybrid Composites Reinforced with Carbon Fibre/ Wollastonite Fibers

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ABSTRACT

In the present study the authors focused on the performance of injection molded short wollastonite fiber and chopped carbon fiber reinforced hybrid polyester composites. The results showed that hybridization of carbon fiber and wollastonite was in congruence to polyester and fibre composite system. Effect of fibre length, fibre orientation in matrix and analysis and fracture surface was undertaken. The mechanical properties of injection molded, chopped carbon fibre/wollastonite/polyester hybrid composites have been investigated by considering the effect of hybridization by these two fillers. It was observed that the tensile, flexural, and impact properties of the filled polyester were higher than those of unfilled polyester. The effect of filler on polyester matrix subjected to the tensile strength and modulus was studied with the help of rule of mixture. The actual results are marginally low compared to the values obtained by the rule of hybrid mixtures.

Keywords: Hybrid fibers, wollastonite fiber, carbon fiber, mechanical properties

I. INTRODUCTION

The interfacial interactions between fillers and polymer matrix play a crucial role in determining the quality and properties of the composites. The poor bonding linkage between the fillers and polymer matrix such as composites made by simple mixing will introduce artificial defects, which consequently result in deleterious effect on the mechanical properties of the composites. Introducing good linkages between the fillers and the polymer matrix is still a challenge for specific composite fabrication. They can be divided into two broad classes, amorphous and crystalline, depending on the type of their characteristic transition temperature. Amorphous thermoplastics are characterized by their glass-transition temperature, Tg, a temperature above which the modulus decreases rapidly and the polymer exhibits liquid-like properties; amorphous thermoplastics are normally processed at temperatures well above their Tg. Glass transition temperatures may be as low as 65 °C for polyvinyl chloride (PVC) and up to as high as 295 °C for polyamideimide (PAI). Crystalline thermoplastics, or more correctly, semicrystalline thermoplastics can have different degrees of crystallinity ranging from 20 to 90%; they are normally processed above the melting temperature, Tm, of the crystalline phase and the Tg of the coexisting amorphous phase. Melting temperatures can be as high as 365 °C for polyetherketone (PEK), as low as 110 °C for low density polyethylene (LDPE), and even lower for ethylene–vinyl acetate (EVA) copolymers. Upon cooling, crystallization must occur quickly, preferably within a few seconds. Additional crystallization often takes place after cooling and during the first few hours following melt processing. Over 70% of the total production of thermoplastics is accounted for by the large volume, low cost commodity resins[1-10]: polyethylenes (PE) of different densities, isotactic polypropylene (PP), polystyrene (PS), and polyvinyl chloride (PVC). Next in performance and cost are acrylics, acrylonitrile–butadiene–styrene (ABS) terpolymers, and high-impact polystyrene (HIPS). Engineering plastics, such as acetals, polyamides, polycarbonate, polyesters, polyphenylene oxide, and blends thereof are increasingly being used in high performance applications. A complex microstructure may result in different fiber orientations at different points of molded specimens. Microstructure characteristics can only explain the in reference for mechanical properties of short fiber composites. The hybridization with small amounts of mineral fibers makes these carbon fiber composites more suitable for technical applications. In a hybrid system various mechanical properties like stiffness strength and fracture toughness depend on the characteristics of constituent fibers like fiber length and fiber volume fraction. When fiber length is smaller than critical fiber length fiber pull out takes place but if fiber length is more than critical fiber length breaking of fiber occurs thus fracture mechanisms can be identified with the knowledge of critical fiber length. Carbon fiber or carbon fibre (alternatively CF, graphite fiber or graphite fibre) is a material consisting of fibers about 5–10 micrometres in diameter and composed mostly of carbon atoms. To produce carbon fiber, the carbon atoms are bonded together in crystals that are more or less aligned parallel to the long axis of the fiber as the crystal alignment gives the fiber high strength-to-volume ratio (making it strong for its size). Several thousand carbon fibers are bundled together to form a tow, which may be used by itself or woven into a fabric. The properties of carbon fibers, such as high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion, make them very popular in aerospace, civil engineering, military, and motorsports, along with other competition sports. However, they are relatively expensive when compared to similar fibers, such as glass fibers or plastic fibers. Carbon fibers are usually combined with other materials to form a composite. When combined with a plastic resin and wound or molded it forms carbon-fiber-reinforced polymer (often referred to as carbon fiber) which has a very high strength-to-weight ratio, and is extremely rigid although somewhat brittle. However, carbon fibers are also composited with other materials, such as with graphite to form carbon-carbon composites, which have a very high heat tolerance. Most polyester resins are viscous, pale colored liquids consisting of a solution of polyester in a monomer which is usually styrene. The addition of styrene in amounts of up to 50% helps to make the resin easier to handle by reducing its viscosity. The styrene also performs the vital function of enabling the resin to cure from a liquid to a solid by 'cross-linking' the molecular chains of the polyester, without the evolution of any by-products. These resins can therefore be molded without the use of pressure and are called 'contact' or 'low pressure' resins. Polyester resins have a limited storage life as they will set or 'gel' on their own over a long period of time. Often small quantities of inhibitor are added during the resin manufacture to slow this gelling action. Vinylester resins are similar in their molecular structure to polyesters, but differ primarily in the location of their reactive sites, these being positioned only at the ends of the molecular chains. As the whole length of the molecular chain is available to absorb shock loadings this makes vinylester resins tougher and more resilient than polyesters. The vinylester molecule also features fewer ester groups. These ester groups are susceptible to water degradation by hydrolysis which means that vinylester exhibit better resistance to water and many other chemicals than their polyester counterparts, and are frequently found in applications such as pipelines and chemical storage tanks. Use of wollastonite in high fraction will reduce the cost of composite and improve tensile strength, impact properties and dimensional stability and yield. High aspect ratio resulting on these wollastonite composites to resist machining and thus has greater surface area, better stress propagation. Reinforcement with wollastonite increases the starting crystallization temperature and induces a shorter processing time in injection molding and thus the effect of crystallinity of the composite for this reason the reinforcement of rotational molded articles with wollastonite is of the interest for research. These materials exhibits increase in flexural modulus, HDT, superior dimensional stability, reduced cost and ease processability. A certain mechanical properties such as strength or modulus of a hybrid system consisting of two single systems can be predicted by the rule of hybrid mixtures as explained earlier. The present work aims to develop chopped carbon fiber and particulate type wollastonite fiber reinforced polyester composites. The composites were prepared by extrusion compounding and using injection moulding techniques [11-20]. In the present research the effects of hybridization by chopped carbon fiber and wollastonite on the tensile and flexural properties of the hybrid PE/CF/WF composites were studied. Since the mechanical properties of carbon fibers and wollastonite differ greatly, the hybrid effect would likely to exist for their hybrid reinforced composites. The hybrid effects have been calculated using the rule of hybrid mixtures for the tensile strength, modulus, flexural strength and modulus.

II. METHODS AND MATERIAL

Polyester (Ecmalon 9911,Ecmas Hyderabad, with 2% cobalt accelerator, catalyst 50% methyl ethyl ketone peroxide (MEKP) in 10% DMA solution, ratio of the resin/accelerator/catalyst:100/2/2. The resin has a density of 1335 kg/m^3, Young's modulus of 450 MPa, tensile strength of 15.3MPa and elongation at break of 3.3%. The grade of wollastonite fiber (WF) used for preparing different compositions was Fillex-11AB3 (surface treated), supplied by Wolkmen India Limited [12, 13]. Tensile strength, three point bending tests were carried out on par with ASTM D 53455. Tensile and flexural tests were performed on Instron universal testing machine (3369). Impact strength of samples was measured on the model number of machine Zwick according to ASTM D 53433. All the tests were accomplished at a room temperature of 20 ºC. At least five samples were tested for each composition and results were averaged. Impact properties were measured in accordance with ASTM D256. The notched Izod test is best applied in determining the impact resistance for many parts with many sharp corners, such as ribs, intersecting walls and other stress concentrator components [15]. The izod strength of notched/un-notched specimens were conducted the impact energy used to break a notched/unnotched specimen is divided by the thickness of the specimen at the notch. It is expressed in kilojoules per meter (kJ/m). Scanning electron microscopy (SEM) studies of the fractured surface of the tensile specimen were carried out on a Jeol (6380LA, Japan). The specimen was sputter-coated with gold to increase surface conductivity. The length of 400–500 carbon and wollastonite fibers from each sample were measured separately and recorded with software [20].

Preparation of the Hybrid Composites

Firstly predetermined amount of polyester resin (matrix) was taken in a by weight based on the mould volume and then mixed with matrix/ promoter/accelerator as 100:2:2 stoichiometric ratios. This solution mixed thoroughly with the help of injection moulding machine.

Table 1 : Illustrations of specimen composites prepared by rule of hybrid mixtures

S.No.	PE (% by wt.)	CF (% by wt.)	WF (% by wt.)
A	100	0	0
B	60	40	0
C	60	30	10
D	60	20	20
E	60	10	30
F	60	0	40

Once it is conform that it is going to form gel then it is going to pour into the a 1/3ed layer of this modified solution on the mould, then carbon and wollastonite fibers are stacked in the randomly oriented direction and make sure that fiber spreads in all directions and then the remaining polyester solution has to poured all over the mould. Using roller a thin OHP sheet is spread all over the top surface of the mould then weight of 50kg load is placed above the OHP sheet [7, 8]. This weight facilitates the uniform distribution of matrix all over the mould, and mirror surface finish when compared with the bottom surface. Carbon and wollastonite fiber are stacked based on the **Table 1** demands. Injection pressure, temperature and back pressures are maintained as mentioned in the **Table 2**.

III. RESULT AND DISCUSSION

The results obtained from mechanical tests are shown in **Table 3**. The results are also obtained graphically in **Figure 1**. It has been found from data that with the incorporation of 40% carbon fiber (specimen B), the tensile strength, tensile modulus, values increased sharply when compared to unfilled material indicating the stiffening effect of carbon fiber.

Table 2 Assumptions made in the injection moulding machine parameter for PE/CF/W composites.

Injection Pressure (%)	Holding pressure (%)	Back pressure	Injection speed	Pressure (N/mm^2)	Injection Temp.(ºC)
64	63	4	80	165-210	70

On the other hand with the incorporation of wollastonite fiber from 10% to 30% by wt, the above values are found to decrease gradually with respect to (specimen B), indicating lower stiffening effect of wollastonite fiber in comparison to carbon fiber.

Sample No.	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at maximum force (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Impact strength (J/m)
A	40.10	414.52	11.52	43.21	1571.66	28.75
B	43.25	645.63	7.42	57.87	3708.42	34.24
C	41.04	563.20	8.85	56.41	3625.02	26.70
D	39.23	538.96	7.85	55.74	3404.86	26.89
E	38.75	594.52	8.05	54.11	3307.56	27.56
F	37.8	963.48	9.24	53.88	3746.05	28.96

Table 3 Mechanical properties of PE/CF/W composites

When compared (specimen A) with (specimen F), it has been observed that there is a little change in tensile strength value between (specimen A) and (specimen F), but the values of tensile modulus of (specimen F) have been found to be higher than that of (specimen F). It has also been found that for the composites (B to F) yield lower values of tensile modulus. On the basis of the above results the authors are of the opinion that the addition of wollastonite content by reducing carbon fiber partially the degree of amorphous nature of polyester decreases.

Length classes(µm)	Vf(CF)=40%Vf(WF)0%	Vf(CF)=30%Vf(WF)=10%		Vf(CF)=20%Vf(WF)=20%		Vf(CF)=10%Vf(WF)=30%		Vf(CF)=0%Vf(WF)=40%
	CF	CF	WF	CF	WF	CF	WF	WF
0-2	0	0	0	0	0	0	0	0
2-4	0	0	0	0	0	0	0	0
4-6	0	0	0.05	0	0.05	0	0	0
6-10	0	0	0.19	0	0.06	0	0.13	0.15
10-20	0.11	0.04	0.42	0.09	0.19	0.09	0.25	0.26
20-40	0.14	0.15	0.41	0.06	0.25	0.05	0.33	0.23
40-60	0.21	0.12	0.05	0.14	0.27	0.16	0.27	0.19
60-80	0.23	0.39	0	0.16	0.09	0.19	0.09	0.12
80-100	0.18	0.05	0	0.15	0.2	0.15	0.1	0.12
100-120	0.16	0.17	0	0.23	0	0.23	0	0.06
120-140	0.05	0.06	0	0.06	0	0.05	0	0.05
140-160	0.07	0.04	0	0.15	0	0.16	0	0
160-180	0.03	0.02	0	0.04	0	0.05	0	0
180-200	0.03	0.08	0	0.04	0	0.07	0	0
200-260	0.05	0.05	0	0.03	0	0.04	0	0
>260	0	0	0	0	0	0	0	0
Mean fiber length(µm)	78.5	110.2	25.36	98.5	40.5	103.8	42.5	48.62

Table 4 Relative frequencies of fiber concentrations.

Tensile stress strain curves of hybrid composites exhibit brittle fracture and show linear deformation under high stress. Measurements of flexural strength and modulus are graphically shown in the **Figure 2**. Flexural strength was increased up to specimen B where after that strength was decreased. On other hand flexural modulus was gradually increases right from the specimen A to specimen F and it was noticed that Specimen F got maximum strength. This non-linear deformation behavior may be related to (1) interfacial microfailure at the fiber ends would have occur in the composites, (2) the microfailure propagates along the fiber lengths, (3) plastic deformation bands in the matrix were observed, and (4) crack opening occurs in the band and the crack grows slowly through the band was observed by Ashok Kumar et al [5].

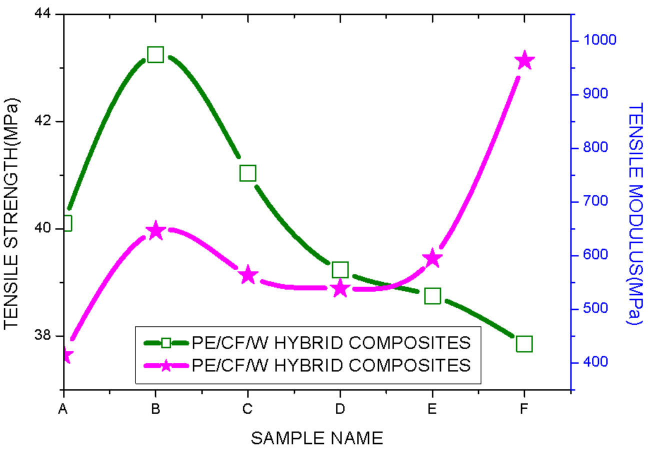


Figure 1: Measurements of tensile strength and tensile modulus of failure strain of the sample.

Finally the catastrophic crack propagation takes place through the matrix pulling out the fibers from the matrix.

The curves shift from right side to left side as the relative wollastonite fiber volume fraction increases. This is due to the fact that the modulus of wollastonite fibers is higher than the matrix but when compared to the glass fibre composite the modulus shows a slight change with the increase in relative wollastonite volume fraction [17]. Moreover, the failure strain of the hybrid composites increases with increasing in relative wollastonite fibre volume fraction as shown in **Figure 2**. This may be partially attributed to the less brittle nature of wollastonite fiber compared to carbon fiber. Furthermore as the wollastonite fiber volume increases there is no significant increase in the strength of the composites. Impact strength was increased for specimen B maximum when compared with the other specimens was shown in the **Figure 3**.

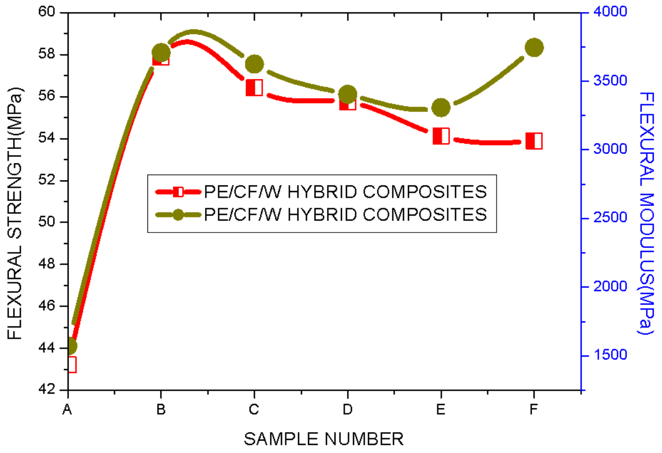


Figure 2 : Measurements of flexural strength and flexural modulus of failure strain of the sample.

The effect of relative wollastonite fiber volume fraction on the mean wollastonite and carbon fiber lengths is presented in **Table 4** & **Figure 4** where the total glass and wollastonite fiber fraction is fixed at 40%. It is of interest to note while observing the trends in mean fiber lengths of both the fibers that with the increase of relative wollastonite fibre volume fraction decreases the mean fibre length relative than the wollastonite fibre due to wollastonite interaction. The carbon fiber and wollastonite fiber length distributions are presented in **Figure 5** which show that fibre length distributions of both carbon and wollastonite fibers shift towards left side as the relative wollastonite fiber volume fraction increases. This figure depicts the cumulative distribution of the fillers in matrix that leads to further study of the fibre distribution.

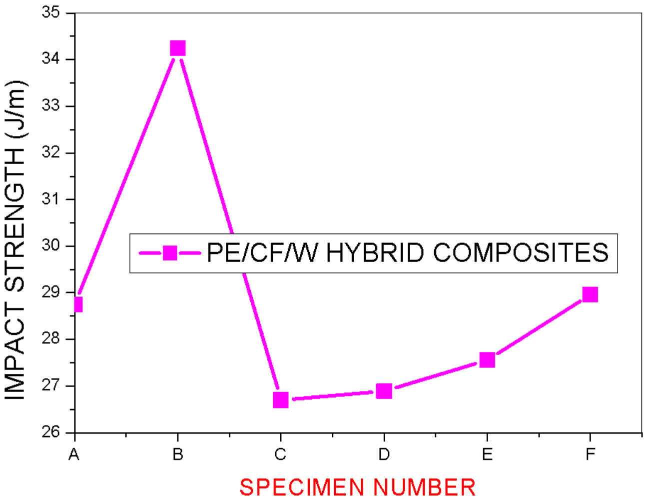


Figure 3 : Measurements of impact strength of failure strain of the sample.

Figure 6 represents the SEM micrographs of fracture surfaces of hybrid composites (specimen D) and (specimen F). The brittle fracture can be easily seen in the composites. It is observed that the short carbon fibre and wollastonite were intimately mixed in the matrix and are distinguishable. Both the figures show that most of the carbon fibers are pulled out. Further it is observed fibers are preferentially aligned in flow direction for these injection molded specimens.

The orientation of fibers is observed morphologically on the specimen sections as shown in **Figure 6** which is the micrographs selected arbitrarily but is a typical one. For both single fibre reinforced and hybrid composites, the fibers are preferentially aligned along the flow direction. This has also been observed in earlier short fiber studies [18].

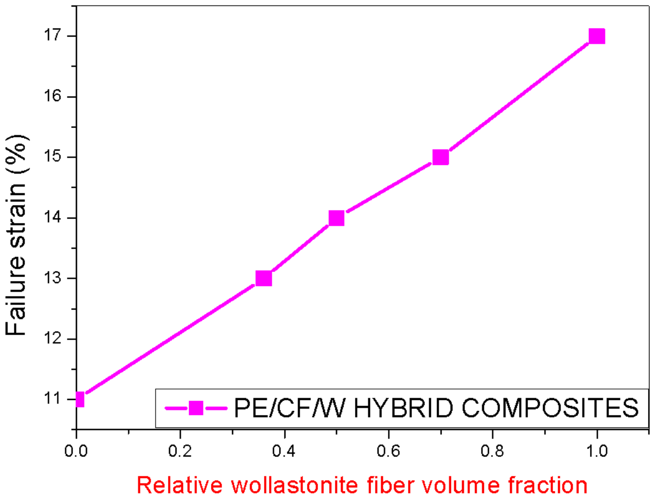


Figure 4 : Measurements of relative fiber volume fractions of failure strain of the sample.

Fiber length measurements were performed by following manually fiber image traces from morphological pictures using Zeiss computerized microscope. Figures below show the results of the RoHM prediction and the strength of hybrid PE/CF/WF composites. **Figure 7** (a) and (b) shows the results of the tensile strength of the hybrid composite. It was observed that, ultimate strength was significantly improved by the incorporation of carbon and mineral fibers. Since the fibers were preferentially aligned in flow direction for these injection molded specimens (see SEM images), in broader view the fiber orientation can be assumed roughly unchanged with the fiber volume fraction. When the relative wollastonite fiber volume fraction increased, there is a slight variation in the mean carbon and wollastonite fiber lengths. When the changes in fiber length were considered to affect, the strength of hybrid composites which was predicted using RoHM as described earlier [12].

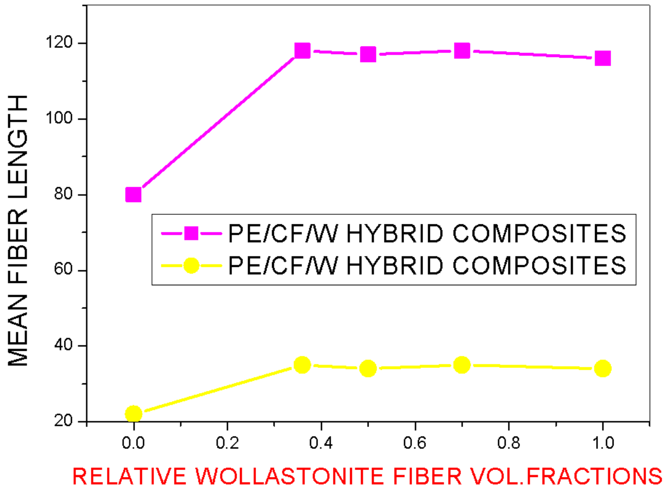


Figure5: Relative wollastonite fiber volume fractions of Vf(WF)/Vf(total).

The predicted values of the tensile strength and modulus measurements for hybrid composite are presented in **Figure 8 (a) and (b).** It can be seen that the experimental values of the ultimate strength of the hybrid composite lie slightly above the predicted values. Thus strength studies exhibits a positive deviation from predicted volumes using and which is evident of fibre addition. Since the wollastonite fiber is slightly less stiff compared to that of carbon fiber and the mean aspect ratios of wollastonite fiber composites were lesser than those of carbon fibers.

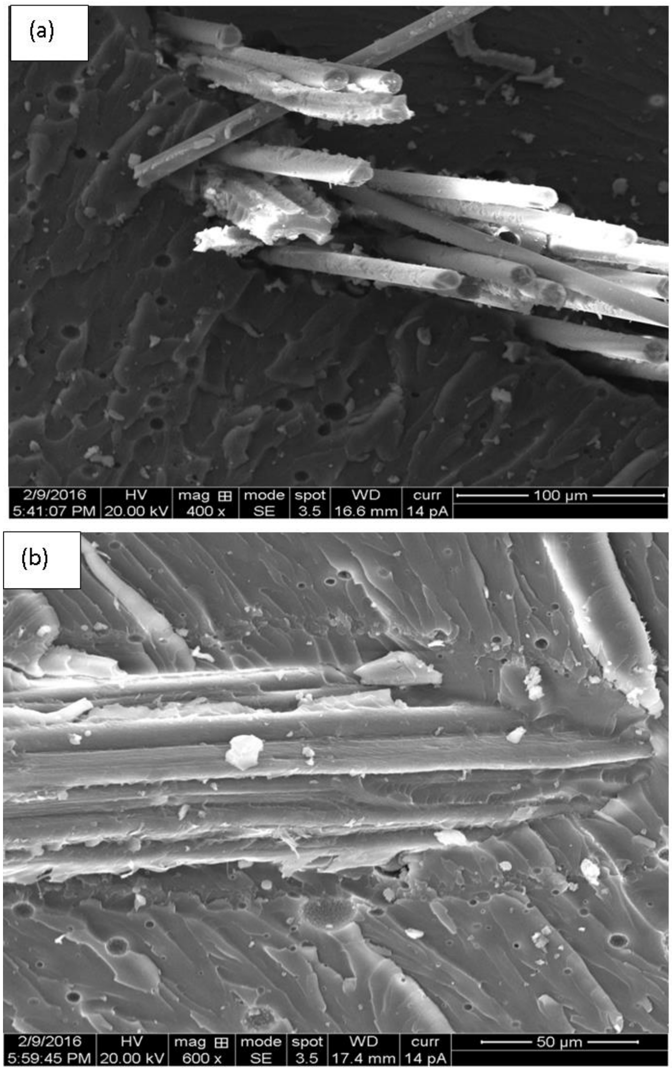
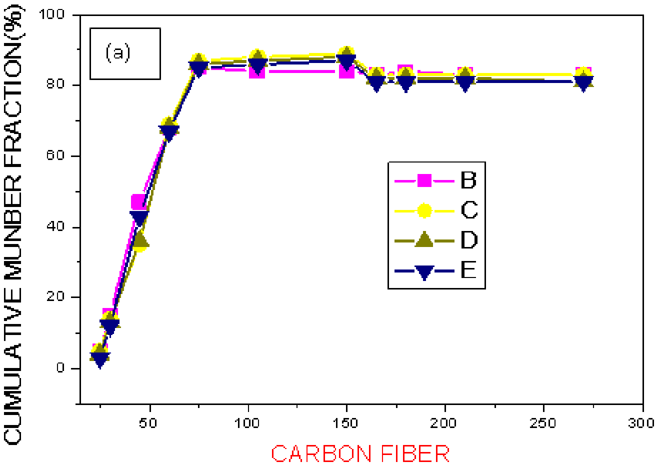


Figure 6: Scanning electron microscope images of specimens of (a) D and (b) F



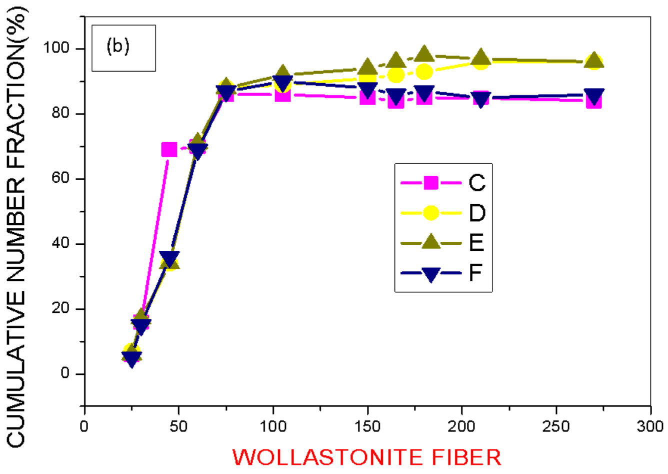
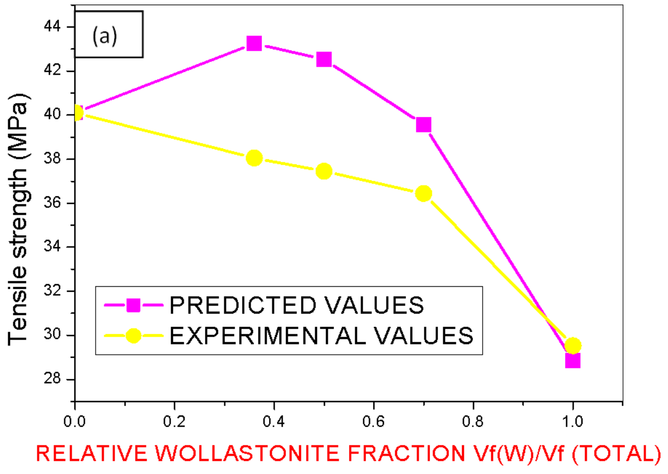


Figure 7: (a) Carbon fiber (b) Wollastonite fiber length distributions of PE/CF/WF hybrid composites.

In the presence of Thus according to the stress transfer theory [16] interfacial debonding would have taken place first at wollastonite fiber ends. Leading to microcrack creation we can say that wollastonite fibers are the source for the micro cracks. As the applied tensile strain or load is increased these cracks propagate along the fibre length and also across neighboring matrix. Carbon fibers these cracks would be bridged by these mineral fibers, allowing the wollastonite fibers to have a slightly larger contribution to the tensile strength of hybrid composites than that of single wollastonite reinforced composites.



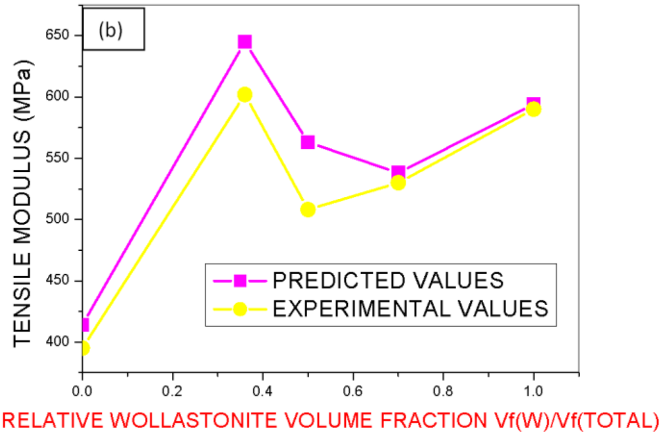


Figure 8: Comparison of experimental values with predicted values (a) tensile strength and (b) modulus of PE/WF/CF hybrid composites.

As a result, a slight encouraging strength of hybrid composites is observed with the addition of these fibers. **Fig. 8(b)** shows the case of tensile modulus. Since carbon fibers are stiffer than wollastonite, modulus was observed to increase with the 100% relative volume of carbon fiber and as wollastonite replaces carbon fiber partially composite modulus decreases with increasing relative wollastonite volume fraction. It can be observed from the figure that modulus of hybrid composites is greatly improved by the addition of both carbon fibers and wollastonite fibers. The modulus decreases slightly with the increase in relative wollastonite volume fraction. The predicted values according to mixture rule lie above the experimental values, indicates that the modulus exhibits a negative deviation from the mixture rule.

IV. CONCLUSION

The mechanical properties of injection molded hybrid polyester composites reinforced with short carbon fibers and wollastonite fibers have been investigated. The results have shown that the tensile strength, tensile modulus, flexural strength, flexural modulus and impact strength of hybrid composites are closed agreement with composites. The elongation at ultimate load and failure strain of the hybrid composites increases slightly with increase in relative wollastonite fibre volume fraction. The effects of fibre reinforced have been studied on the tensile properties of the hybrid composites. A positive effect has been observed in the ultimate strength while negative effect was noted for the tensile modulus.

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