MECHANICAL, PHYSICAL, AND WEAR PROPERTIES OF POLYPROPYLENE REINFORCED SHORT CARBON FIBER COMPOSITES WITH DIFFERENT FIBER LENGTH

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ABSTRACT

The objective of this research is to study the effect of short carbon fibers (with different fiber length) on the mechanical, physical and wear properties of polypropylene reinforced short carbon fiber composites. Polypropylene reinforced short carbon fiber (SCF) composites with different weight% were fabricated using twin-screw extruder followed by injection molding to produce PP-SCF composites. Fiber diameter of 7-9 μm with two different fiber lengths, 90 and 150 μm, were used in this study. Five different composition were processed, 5, 10, 15, 20, and 35 wt %. Mechanical properties were evaluated by tensile test. Differential Scanning Calorimetry (DSC) and Thermogravimetric Analysis (TGA) were used to evaluate the physical properties of the composites. Tribology properties were studied by ball-on-disk for wear resistance property. The morphology of the composites were analysed using Scanning Electron Microscope (SEM). The properties of the composite in general have increased as a function of the filler content.

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1 INTRODUCTION

Thermoplastics have become very common material used in our daily life. Thermoplastic materials have limitations because of their poor mechanical properties. However, thermoplastic materials are widely used in automotive industry due to their lightweight, process ability and recyclability [1].

Several investigations were performed which intended to improve the mechanical and physical properties of thermoplastic materials. Polymer blends [2], continuous-fiber reinforced thermoplastic [3], long-fiber reinforced thermoplastic [4], short-fiber reinforced thermoplastic [5], and nano-filler [6-9] reinforced thermoplastic are some of technique used to improve the properties of the thermoplastic polymers.

Short-fiber reinforced thermoplastic composite is widely used. One of the advantages short fibers is its process ability. However, the strengthening effect after the incorporation of short fibers is not as expected.

Compatibility between matrix and fiber is critical as it forms the basis for interfacial bonding. Without strong interfacial bonding, load transfer from matrix to fiber tends to be limited. As a result, the increase in strength and stiffness in the composite is not proportional to the strength of the fiber itself [10]. Compatibilizer or interfacial bonding agent is required to improve the interfacial bonding between matrix and fiber. Since polymers are organic materials and most of the fillers are inorganic, compatibilizer is needed to increase the interfacial bonding. Maleic Anhydride as compatibilizer is the most common material used to create interfacial bonding between polymer and inorganic fillers [10].

Different shape, surface, mechanical, and physical properties of filler influence the properties of thermoplastic composite differently. Some studies show that the addition of spherical shape e.g. silica nanoparticle, improves the toughness and elasticity [11], while addition of similar particle in fiber shape will increase modulus of elasticity and strength [10].

Recently, a combination of micro-scale with nano-scale filler has been an area of significant interest. The use of small amount of nano-reinforcement is expected to increase the interfacial shear stress between the matrix and macro-filler that lead to the improvement in the properties of the composites[12].

Yang et al. [13] reinforced PP grafted maleic anhydride with MWNT–NH2 by a reactive blending process and observed significant improvement in the mechanical properties of the developed PP nano-composite. They reported that an addition of 1.5 wt.% of MWNTs has increased the Young's modulus, tensile strength, ultimate strain and toughness of PP by 108, 141, 49 and 287%, respectively.

Yang et al. [14] reported that Poly (arylene ether nitrile) (PEN)/Carbon fiber (CF)/Graphene nanoplatelet (GNP) composites, prepared by the twin-screw extrusion, exhibited excellent mechanical properties. The flexural modulus at 20 wt.% CF and 10 wt.% GNP of PEN/CF/GNP composites was 18.6 GPa, which is 1.7, 4.5 and 6.4 times higher than those of PEN/CF composites, PEN/GNP composites and pure PEN, respectively. While, significant increase of the impact strength is also observed when GNP content is 5 wt.%. At that point, the impact strength of PEN/CF/GNP composites was 12.14 J/m2, which was increased by 98.4%, 63.6% and 29.4% compared with those of pure PEN, PEN/GNP and PEN/CF composites, respectively.

In this study, composite of polypropylene and short carbon fiber composite (PP-SCF) are developed. Different SCF ratios were used ranging from 5 to 35wt% SCF. The carbon fiber used are of two different length, 90 and 150mic. The effect of fiber length and fiber content on the physical, mechanical, and wear properties of the composite were investigated.

2 MATERIAL AND EXPERIMENTAL PROCEDURE

2.1 Materials

The materials used in this study are short carbon fiber (SCF) with different fiber length and Polypropylene polymer. The SCF used is Asbury Carbons AGM94 and is considered a Conductivity Enhancer material supplied by Asbury Carbons. Polypropylene used is developed by SABIC company and the grade used is PP 500P. Table 1 and Table 2 represent the properties of SCF and PP used in this study.

Properties		Value
Melt Flow Rate	g/10min	3
Density	Kg/m^3	905
Tensile strength	Mpa	35
Tensile Elongation	%	10
Flexural modulus	MPa	1500
Notched IZOD impact strength @23C	J/m	25

Table 1: Properties of Polypropylene (PP 500P)

Properties		Value
Grade	-----	AGM94
Type	-----	Pitch
Fiber Diameter	Microns	7-9
Density	g/cc	1.73-1.79
Carbon	%	94
Tensile strength	GPa	2-3.8
Young's modulus	GPa	180-240

Table 2: Properties of short carbon fiber (Asbury)

2.2 Processing

The short carbon fibers are mixed with Polypropylene granular and then extruded using Lab Tech 16mm Twin Extruder machine. Different SCF composition ratios were processed ranging from 5-35wt%. Testing samples were produced using Injection Molding (Chen Hsong- JM138). Different testing samples were produced to cover different tests (Figure 1).

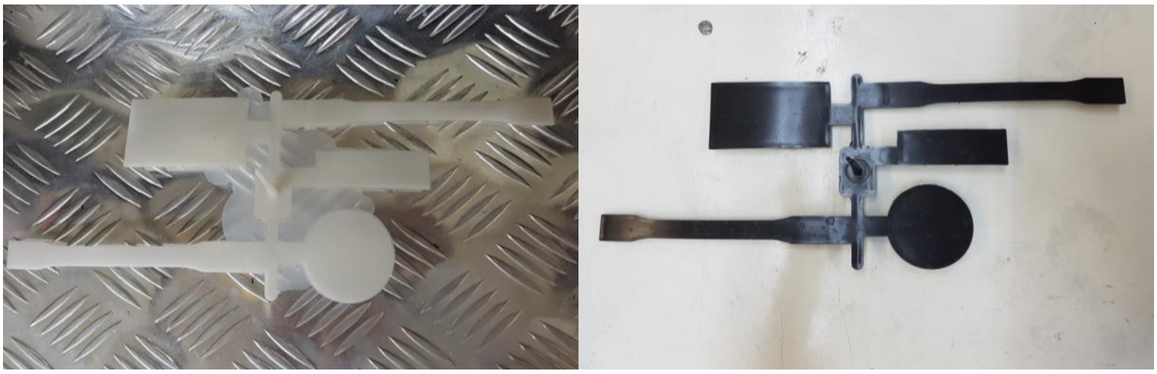


Figure 1: Testing samples produced by injection molding.

2.3 Physical, Mechanical, and Wear Properties

Thermogravimetric Analysis (TGA)

Thermogravimetric analysis measures the weight change of a material as a function of temperature (or time) under a controlled atmosphere. The experiments were conducted with a heating rate of 10°C /min from room temperature to 600°C under air atmosphere. Therewith, the degradation behavior of PP-SCF composites were analyzed.

Differential scanning calorimetry

The glass transition temperature PP-SCF composites were determined using differential scanning calorimetry. Conventional DSC experiments were performed at 10°C/min from room temperature to 600°C.

Scanning Electron Microscopy

Scanning Electron Microscope (SEM) was used to characterize the morphology of the composites. JOEL JSM-7600F was used to understand the degree of dispersion of SCF on the PP matrix.

Tensile Test

Tensile tests were conducted on PP-SCF composite to measure the strength, stiffness, and ductility. Tensile testing was conducted using Instron Testing Machine with cross head speed of 5mm/min.

Wear Test

Bruker UMT TripoLab machine was used to measure the wear resistance and weight loss in the composites. Load of 50N was applied on each sample for 5 hours at a speed of 60rpm.

3 RESULTS AND DISCUSSION

3.1 Thermal Properties

Figure 2 shows the DSC-TGA graph of PP-10wt%SCF (150 micron length). DSC can measure the Glass transition temperature of the composites which is at 165°C. TGA shows the degradation temperature at about 450°C. TGA can measure weight loss due to degradation. This is useful to measure the filler content to compare with intended filler percentage.

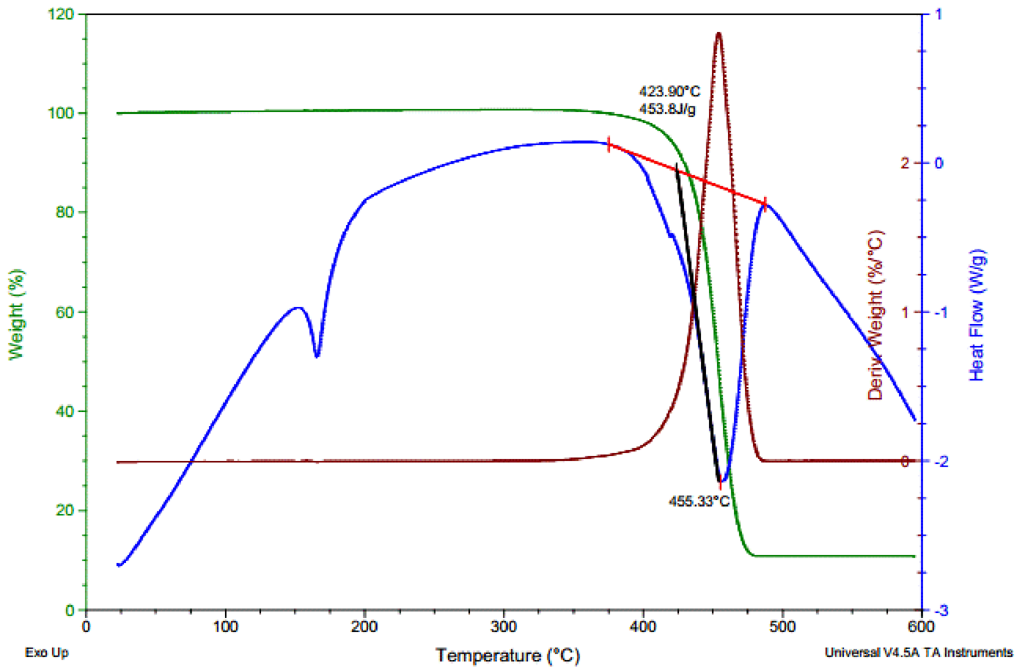


Figure 2: DSC-TGA analysis of PP-10wt%SCF (150micron length)

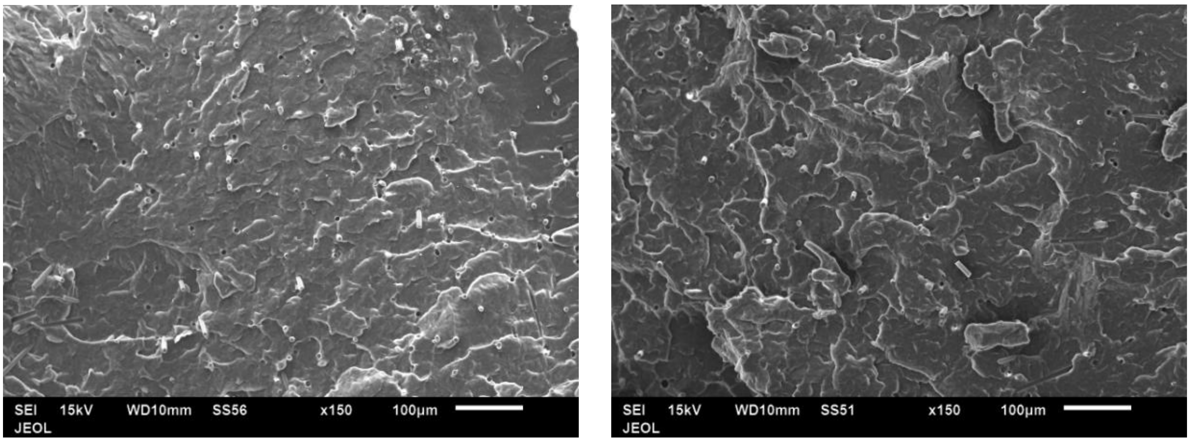
Table 3 shows the glass transition temperature and SCF content in each composite patch. It can be seen the addition of SCF on the PP matrix did not change the glass transition temperature and remain at 165°C which is similar to pure PP. The measured values of SCF content in the composite using TGA gave data similar to the indented processed composites.

Fiber content	pp	TGA Fiber content	Melting point
0%	Pure PP	0%	165 C
5%	SCF90µm	4.42%	165 C
	SCF150µm	5.07%	165 C
10%	SCF90µm	10.99%	165 C
	SCF150µm	10.81%	165 C
15%	SCF90µm	15.10%	165 C
	SCF150µm	15.88%	165 C
20%	SCF90µm	20.05%	165 C
	SCF150µm	20.30%	165 C
35	SCF90µm	35.96%	165 C
	SCF150µm	36.20%	165 C

Table 3: Melting Point of the PP-SCF composites.

3.2 Composite Morphology

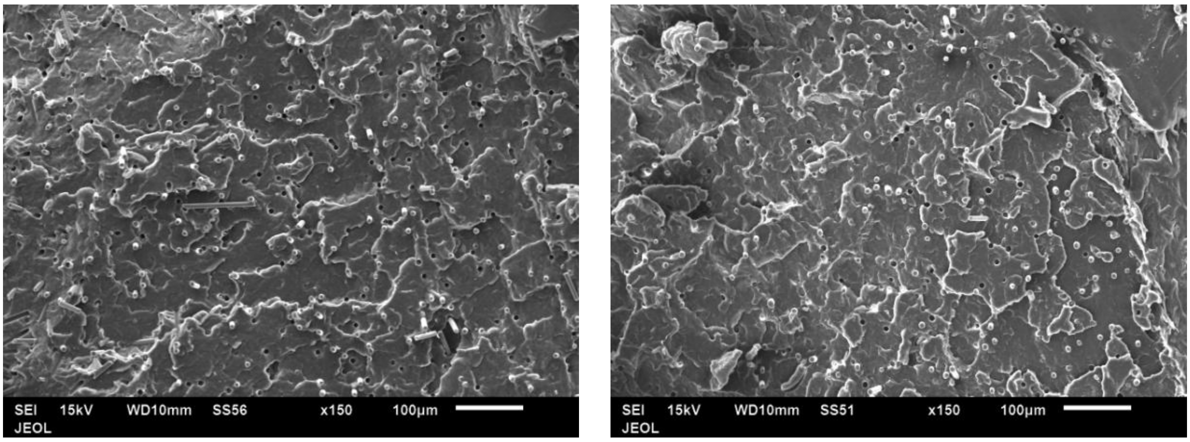
The morphology of the composite was investigated using Scanning Electron Microscope. The composite sample was immersed in liquid nitrogen and then cut. Figure 3 and Figure 4 shows the morphology of the composite samples for two different composition, 5wt% and 15wt% SCF. Figure 3 show the morphology of PP-5wt%SCF for 90mic and 150mic length size. Similarly, Figure 4 shows the morphology of PP-15wt%SCF for 90mic and 150mic length size. It can be seen from the graph that the SCF's were nicely dispersed in the PP matrix. It can be noticed that there are some pull out fiber because of the immersion of the sample in liquid nitrogen.



a) PP-5wt%SCF, 90mic length

b) PP-5wt%SCF, 150mic length

Figure 3: SEM graph of: a) PP-5wt%SCF, 90mic length, b) PP-5wt%SCF, 150mic length



a) PP-15wt%SCF, 90mic length

b) PP-15wt%SCF, 150mic length

Figure 4: SEM graph of: a) PP-15wt%SCF, 90mic length, b) PP-15wt%SCF, 150mic length

3.3 Tensile Test

Figure 5 shows the stress strain diagram for pure PP and different PP-SCF composites at cross head speed of 50mm/min. Figure 6 shows the tensile strength of the composite for different SCF ratio. The effect of content of the SCF on the composite performance was low up to 20wt%SCF. At 35wt%, the tensile strength increase to about 65MPa which is more 100% of pure PP. The effect of SCF length did not have much influence in the tensile strength. PP-SCF 90mic length has somehow similar values as PP-SCF 150mic length.

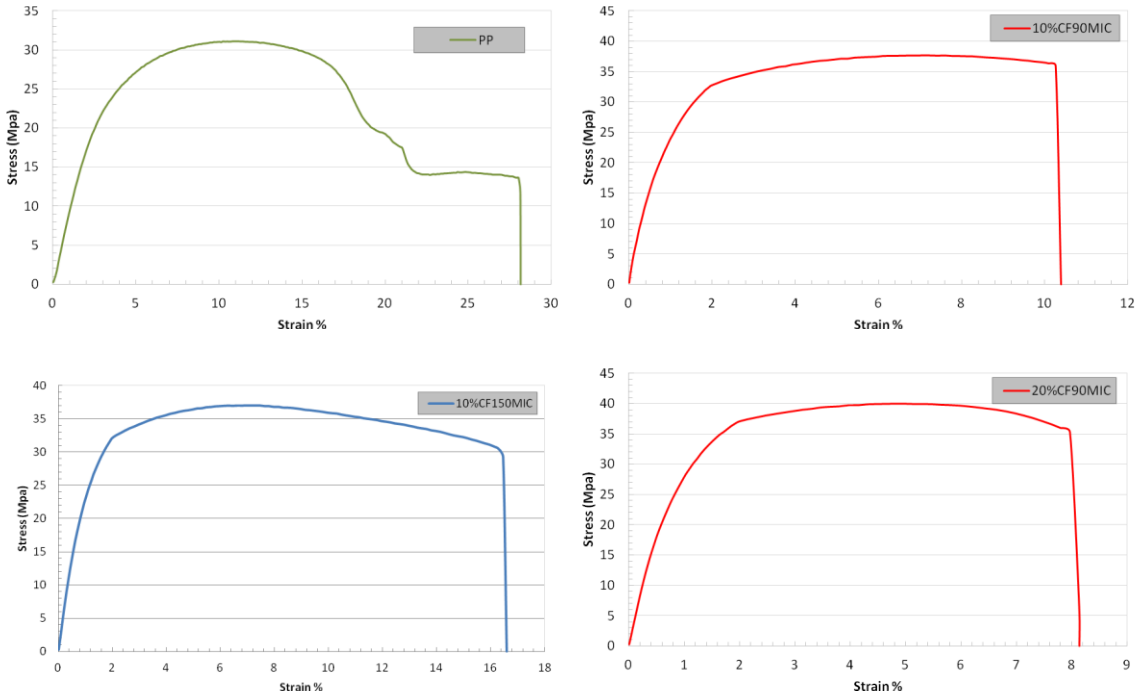


Figure 5: Stress Strain Diagram PP-SCF composites.

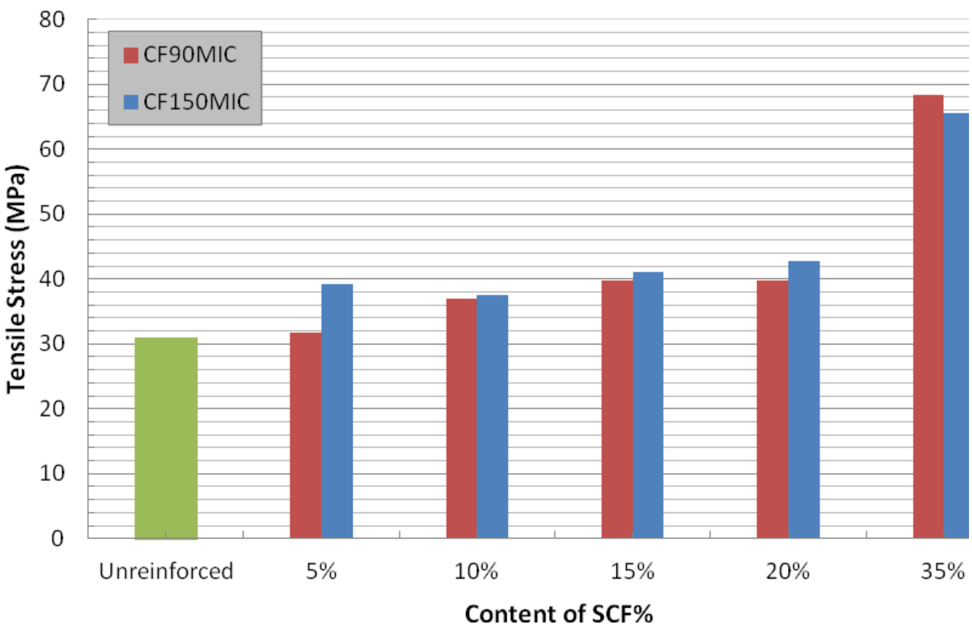


Figure 6: Tensile strength of composite for different content of SCF.

Figure 7 shows the modulus of elasticity of the composite for different SCF ratio. The effect of the SCF content on the modulus of elasticity is more pronounced here compared to the tensile strength case. The modulus of elasticity is steadily increased with the increase of SCF. Similar jump in modulus of elasticity occur at 35wt% SCF. The effect of fiber length on modulus of elasticity is clear in the figure. SCF of 150mic length has greater influence in the composite compared to SCF 0f 90mic length. Modulus of elasticity of PP-35wt%SCF of 90mic reaches 6.5GPa which is 4 times the value pure PP. On the other hand, Modulus of elasticity of PP-35wt%SCF of 150mic reaches 9.4GPa which is 6 times the value pure PP and 50% more than that of PP-35wt%SCF of 90 mic.

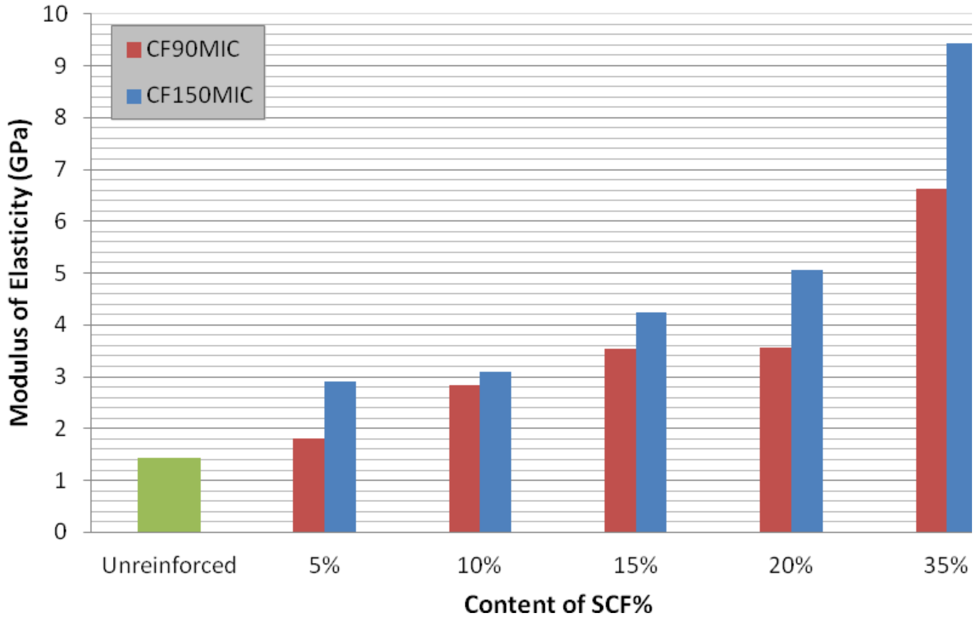


Figure 7: Modulus of Elasticity of composite for different content of SCF.

As expected, the elongation has dropped as a function of SCF content (Figure 8). The ductility of pure PP reaches 28% and drop to almost 2% for PP-35%SCF. The fiber length has pronounced influence on the ductility at 5wt% SCF. At SCF ratio above 5wt%, the fiber length did not show much influence.

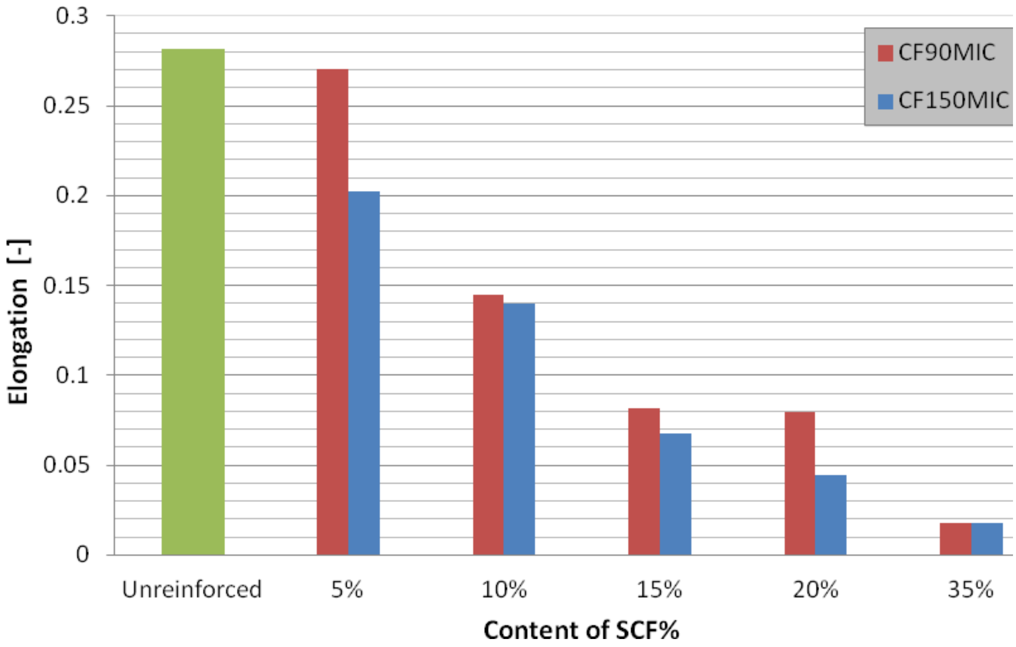


Figure 8: Elongation of composite for different content of SCF.

Table 4 presents the different properties measured for different SCF content for two different SCF fiber lengths. The table also present the elongation measured at two different strain ratios. At high strain rate (cross head speed of 50mm/min), the ductility for pure PP reached 28%. At low strain rate (cross head speed of 5mm/min), the ductility of pure PP reached 660%. This clearly indicates the dependence of the ductility on the strain rate. The table also shows the percentage change in properties of PP-SCF composites compared to pure PP. The change in tensile strength for PP-SCF 90mic was similar to that of PP-SCF 150mic where the improvement reached about 120% of the tensile strength of pure PP.

		Property				% change in properties		
Material	Fiber Content	Tensile Strength (MPa)	Modulus of Elasticity (GPa)	Elongation [50mm/min]	Elongation [5mm/min]	Tensile Strength	Modulus of Elasticity	Elongation
PP	0%	30.9	1.44	28%	660%	------	------	-----
PP + SCF 90	5%	31.6	1.8	27%	560%	2.3	25.6	-3.9
	10%	36.9	2.8	14%	370%	19.6	96.7	-48.5
	15%	39.7	3.5	8%	8.2%	28.6	144.9	-71
	20%	39.8	3.5	8%	5.9%	28.7	146.0	-71.7
	35%	68.4	6.6	1.7	2.4%	121.3	359.6	-93.7
PP+ SCF 150	5%	39.1	29	20%	620%	26.5	101.8	-28.2
	10%	37.4	3.1	17%	139%	21.1	113.9	-50.3
	15%	41.1	4.2	7%	5.6	32.9	194.3	-76.
	20%	42.7	5.0	4%	4.5	38.2	249.7	-84.3
	35%	65.5	9.4	1.7%	2%	111.8	553.8	-93.6

Table 4: Mechanical Properties of PP-SCF composites and Properties Improvement.

In the case of modulus of elasticity, the effect of fiber length was more pronounced. The modulus of elasticity of PP-35wt%SCF with 90mic fiber length improved to 360% of that of pure PP. In PP-35wt%SCF with 150mic, the modulus of elasticity improved to 550% of that of pure PP. The drop in the ductility was the same for both fiber lengths for PP-35wt%SCF. The drop in ductility is about 94% reduction compared to pure PP. Figure 9 illustrate the ductility PP-SCF composites at low strain rate (cross head speed of 5mm/min). The ductility of the composites drops as function of SCF 90mic content. There is a huge transition in ductility as the percentage of SCF increase above 10wt%. As shown in the figure, the ductility dropped from 370% at PP-10wt%SCF to 8% at PP-15%SCF. Similar trend occur for SCF 150mic. This might be due intercolation of fibers at this weight percent.

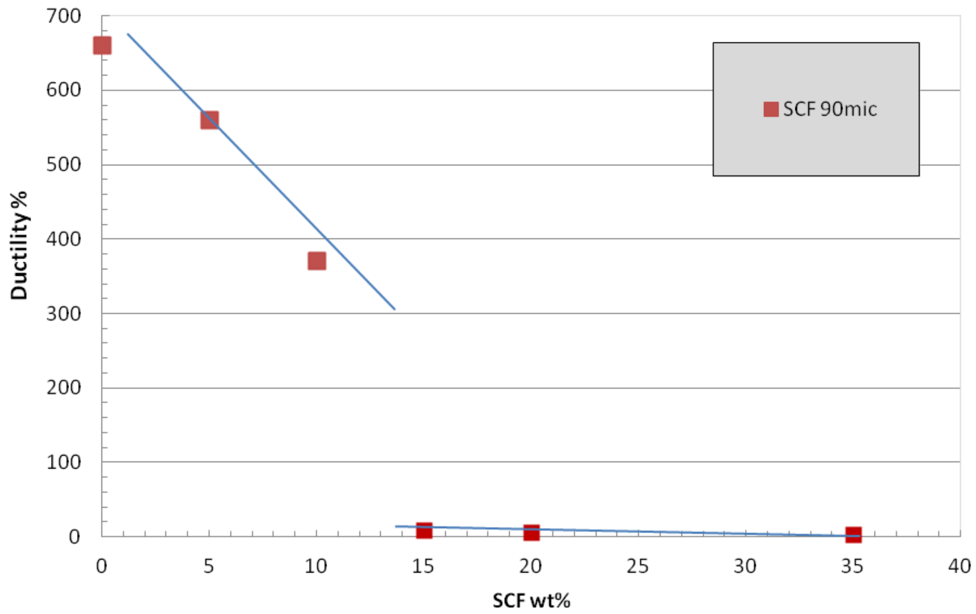


Figure 9: Ducility of PP-SCF composite at low strain rate (cross head speed 5mm/min).

3.4 Wear Test

Wear test was conducted using ball on disk technique. 10mm diameter steal ball was rotating on composite sample surface while applying load of 50N. The test duration was 5 hours.

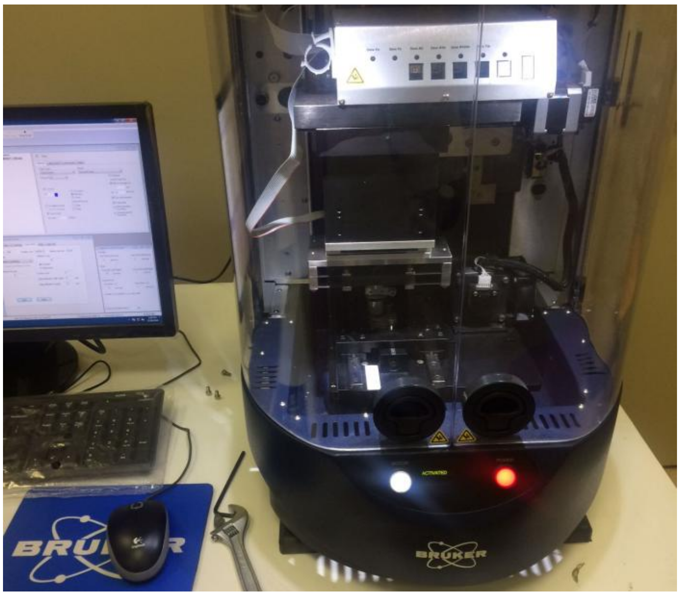


Figure 9: Bruker Tribology Testing Machine

Once the test is completed, the weight of composite is measured and compared to the original weight of the composite to measure the weight loss. is the interactions between two material surfaces resulting in some material removed from one of them or both. Figure 9 shows the tribology testing machine. The machine is computerized and the operator needs to set the weight required and the time for the machine to run. The weight loss can be measured using a precise weight scale. Table 5 shows the weight loss for PP-SCF composites.

PP+CF150	5%	10%	15%	20%	35%
Original weight	7.2953	7.5567	7.7241	7.7684	8.4103
Final weight	7.2495	7.4891	7.6514	7.695	8.4052
Weight loss	0.0458	0.0676	0.0727	0.0734	0.0051

Table 5: Weight loss for PP-SCF 150mic composites

The wear study was conducted on SCF 150mic only. The weight loss increased with increasing SCF content up to 20wt%SCF. At PP-35wt%SCF the weight loss drops to a very low value reaching 0.5% of the original weight. Figure 10 show the variation in weight loss as a function of SCF content for the 150mic fiber length. The weight loss increase and reaches a maximum at 20wt%SCF which is contradictory to the expect results. At 35wt%SCF the weight loss drops to a very low value. This is somehow puzzling situation and further studies are needed to understand or to verify this case.

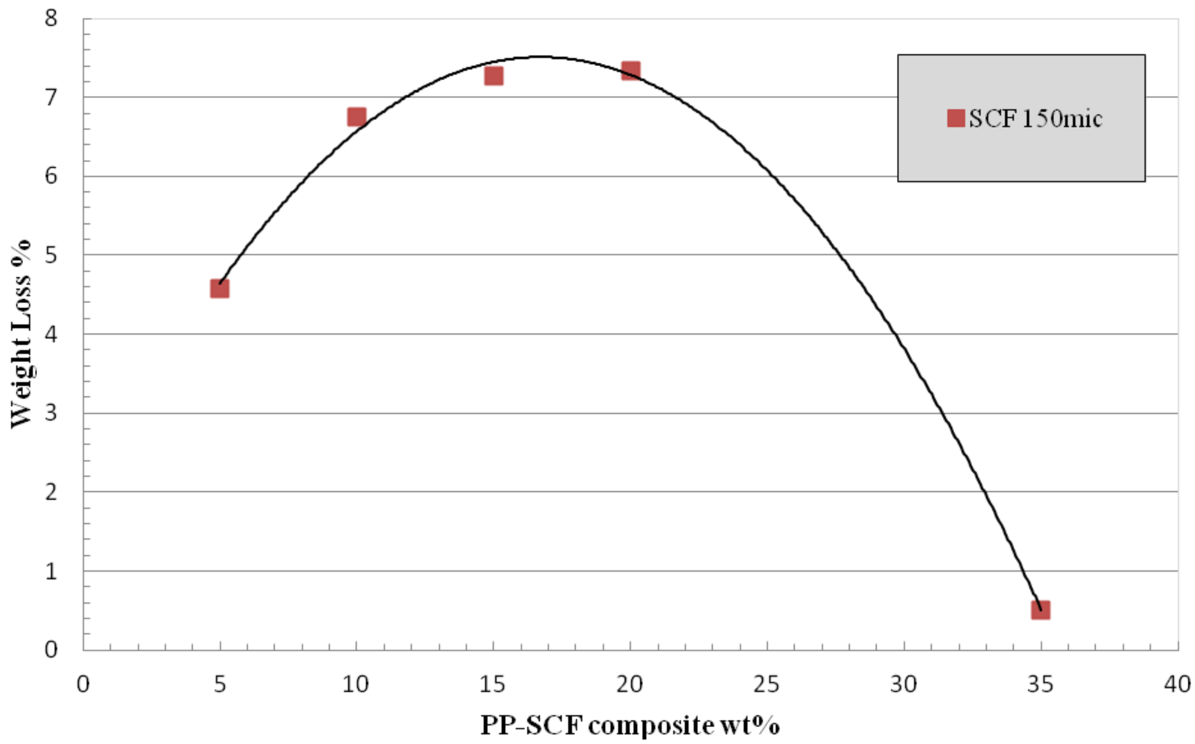


Figure 10: Weight loss for the PP-SCF composites.

4 CONCLUSIONS

The tensile strength and modulus of elasticity increase with the increase of the SCF content. The effect of SCF was more pronounced in the modulus of elasticity compared to tensile strength. Ductility on the other hand has reduced as a function of SCF content. The fiber length affected the modulus elasticity while the effect of fiber length was minimal in the tensile strength and ductility. The wear properties as a function of the SCF content were not as expected. The weight loss increases with the increase of SCF up to PP-20wt%SCF. At PP-35wt%SCF the weight loss drops to a very low value. Further investigation of the wear properties need to be conducted to have a better understanding on the wear behaviour as a function of SCF content.

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