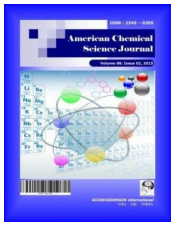

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Investigation on Tensile Properties of Polymer Composite Based on Polypropylene, Polyamide Fiber and Carbon Black

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Authors' contributions

This work was carried out in collaboration of both authors. Author AMKN designed the study, interpreted the results, and prepared the final manuscript. Author AAAA managed performed the analyses and literature searches of the study. Both authors read and approved the final manuscript.

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ABSTRACT

Polymer composites are important class of materials. Some of these composite composites display tremendous mechanical properties. The combination of artificial fiber with polypropylene matrix has affected its matrix mechanical properties. The main objective of this work was to study the tensile properties of the polymer composite made from polypropylene, carbon black powder and polyamide fiber. The composite sheets were prepared using hot press compression method at different processing temperatures and period of times. The composite chemical composition was varied by changing the components weight percentage. Tensile test was used to evaluate the effects of the processing temperature, time and the chemical composition. The results indicated that the processing temperature has enhanced the maximum force at yield, tensile stress, breaking force and elongation at break while processing time and carbon black powder content have reverse effects except for the elongation at break for carbon content. The optimum fiber content to achieve

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the maximum force, tensile stress and break force was 12.29%. Elongation at break was also increased when carbon black powder and fiber contents increased to 0.175% and 9.22%, respectively. It was clearly that the application of polyamide fiber in polypropylene composite has influenced the tensile properties of polypropylene composite.

Keywords: Polypropylene composite; polyamide fiber; tensile stress; carbon black.

1. INTRODUCTION

Fiber reinforced polymers are among composite materials consisting of polymeric matrix imbedded with high strength fibers. Application of synthetic and natural fibers as reinforcement materials in polymer composites have attracted interest and become one of the interesting subjects of scientific research [1-3]. Mechanical properties of a polymeric composite are important topic to achieve good understanding of the polymer behavior during production processes and applications. It also provides data regarding the improvement of polymer properties when blended with other materials such as filler and reinforcement fibers.

Natural fibers are renewable and biodegradable material and have been used in fiber reinforced polymer materials in polymer composite [4]. Several studies on fibers such as jute fiber [5-7], flax fiber [8], hemp fiber [7], pineapple leaf fiber [9] and rice hull fiber [10] in fiber reinforced polymer composite have been reported. However, due to the biodegradability characteristic of this class of material on the surface layers, particularly when subjected directly to relevant conditions such as sun light, humidity and temperature, in long term applications may have undesirable impacts on the mechanical properties of the composite.

Polyamide fibers are synthetic fibers and used in many industries for example manufacturing of tires and fishing nets. The fibers have many advantages including exceptionally strength, elastic, abrasion resistant, resistance to damage from oil and many chemicals and low moisture absorbency. In addition, resistance to photo-degradation is also a property determines the durability of the material. Exposure to sunlight was known to degrade most of the natural fibers, and the developed synthetic polymer materials. Resistance to light and weathering was much the same in all-vegetable fibers, while synthetic fibers showed very great differences in that respect [11]. To avoid any degradation in long time polymer composite applications, polyamide fiber can be used as reinforcement material like glass and carbon fibers [12], rayon fiber [13] and carbon nanotube [14] in polypropylene composites. In addition, fiber reinforced polypropylene composites exhibited high strength, durability and moisture resistance properties [15]. The aim of the present study is to investigate the effects of the polyamide fiber and carbon black powder on the tensile properties of polypropylene composite. The effects of processing temperature and time on the properties are also investigated in the experiments.

2. MATERIALS AND METHODS

2.1 Materials

Polypropylene random copolymer used in this work is classified as RA130E-1498 grade imported from SK Corporation, Korea. This grade complies with material requirements of DIN 8077, DIN 8078, and ISO 15874-1.2. Its melting temperature was 173°C and melt flow index was 10.25 g/10 min at 230°C and 2.16 kg. Its density at room temperature was 905 kg/m^3. Polyamide fiber of a code number of 614.70.90 consists of very thin fiber with linear density (dtex) of 1400 × 2 and Twist yarn (T/M) of 390±152 obtained from Tires Manufacturing Plant as a gift. The polyamide fiber was grounded to small lengths ranged from 0.5 to 2 mm using Ball Miller equipment. Carbon black powder was also obtained from Tires Manufacturing Plant, Libya as gift and used without any treatment or purification. Its specific gravity and its surface area at 20°C were 1.75 – 1.85 g/cm^3 and 38 – 48 m^2/g, respectively.

2.2 Sample Preparation

Due to the differences in the densities, shapes and sizes of the polypropylene pellets, carbon black powder and polyamide fiber, pretreatment of the mixture was carried out. The mixture with specific weight ratio was physically mixed and heat at 100±10°C in thermostatic steel vessel for few minutes. This process is carried out to attach the carbon black powder and the fiber on the

surface of the polymer pellets. The weight percentages of polyamide fiber and carbon black powder in the composite were varied from 3.07% to 15.38% and from 0.061% to 0.298, respectively. The obtained composite is used to produce a sheet using compression mold technique. Dimensions of mold were 150 mm x 100 mm x 2 mm. Pre-calculated weights of polypropylene, carbon black powder and polyamide fiber was added to the middle of the sheet mold which previously placed on the lower plate of a compression machine. The top and the bottom surfaces of the mold were covered by polyamide film obtained from local market in order to avoid the adhesion of the polymer composite on the surfaces of the mold. The composite sheet was produced by using Hydraulic Press HNO.500-7, heated to certain temperature for specific period of time and pressed to 100 bars. The processing temperature for the preparation of the composite sheets was changed from 170°C to 200°C by the interval of 10°C. After that, the mold was cold to room temperature by immersing it in water. The sheet then extracted from the mold prior to characterization.

2.3 Experimental Design

The chemical composition of the composite and the processing parameters have dramatic effects on the mechanical properties of the polymer composite sheet. The sheets of different compositions were produced at different processing temperature and time. Table 1 illustrates the experimental design for the produced composite sheet.

2.4 Tensile Test

Mechanical testing is an important analysis when designing the plastic materials and evaluating its applications. Tensile test for the produced composite sheets at ambient conditions is carried out by using Universal Tensile Tester TIRA test 2850-SE12 according to ISO 527-2 procedures. Three dog bone specimens from each produced sheet was punched and subjected to investigation. The velocity of the tensile tester was adjusted to 2 mm/min and the results reported in form of maximum force at yield point, tensile stress, elongation at break and breaking force.

3. RESULTS AND DISCUSSION

The results on mechanical properties such as maximum force at yield, tensile stress, breaking force, and elongation at break of the composite are presented in Figs. 1 through 8. Temperature of 160°C was insufficient to complete melting of the composite and produced the sheets at 7 min heating. Temperature above 200°C was not used to avoid occurrence of any thermal degradation of the polypropylene under the experimental conditions. The maximum force at yield point at which the polypropylene chains start to slip from each other has been measured. Fig. 1 presents the effects of processing temperature on maximum force at yield point and tensile strength. It is very clear that the processing temperature has small limit effect on the tensile strength of the produced sheets. In addition, the maximum force increases up to about 20% when the temperature increased to 200°C. The increase in the values of maximum force and tensile stress of the constant composition at different processing temperatures could be due to the interfacial adhesion between the materials and, as a result, improve stress transfer between the phases.

Fig. 2 shows the relationship between processing time with respect to breaking force and elongation at break at constant composition and temperature. Similar trends in the values of both results are clearly recorded. Generally, a reduction in the maximum force and tensile stress values is observed when the processing time for the production of the composite sheets was increased. This reduction maybe attributed to that the heating of polymer composition for relative high periods of time at constant temperature has led to partial thermal degradation of the polymer chains and weakened the composite. The maximum force and tensile stress values are also decreased when the carbon black powder content in the sheet composition at constant processing temperature and time was increased (see Fig. 3). This reduction in the recorded values may be due to lower interfacial adhesion of the polypropylene chains on the carbon particles surface. In addition, the increase of the carbon black powder content in the polymer matrix may cause discontinuity in polypropylene matrix, consequently, leading to a low stress transfer between the phases.

Table 1. Experimental parameters for the composite sheet

Group No.	Polypropylene (Wt%)	Fiber (Wt%)	Carbon back (Wt%)	Temperature (°C)	Time (min)
	96.85	3.07	0.061	170	7
1	96.85	3.07	0.061	180	7
	96.85	3.07	0.061	190	7
	96.85	3.07	0.061	200	7
	96.85	3.07	0.061	180	6
2	96.85	3.07	0.061	180	7
	96.85	3.07	0.061	180	8
	96.85	3.07	0.061	180	9
	93.78	6.14	0.061	180	7
3	90.70	9.22	0.061	180	7
	87.63	12.29	0.061	180	7
	84.54	15.38	0.061	180	7
	96.80	3.07	0.122	180	7
4	96.75	3.07	0.175	180	7
	96.68	3.07	0.245	180	7
	96.63	3.07	0.298	180	7

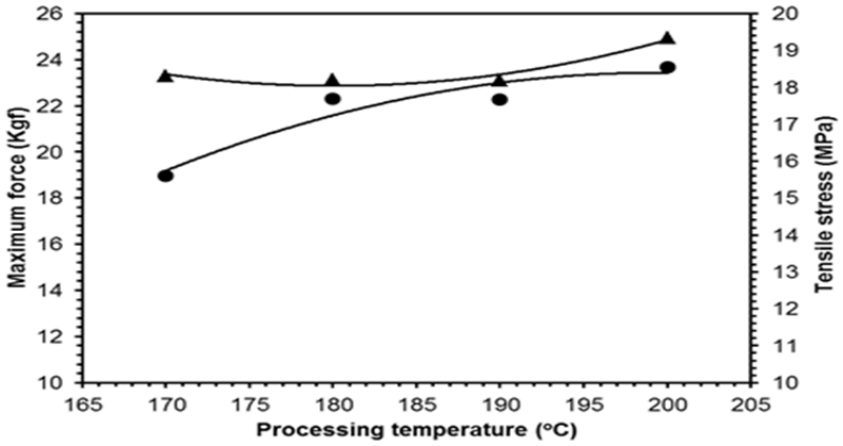

Fig. 1. Effect of different heating temperatures on Maximum force at yield point and tensile stress of the composite [●= maximum force; ▲= tensile stress]

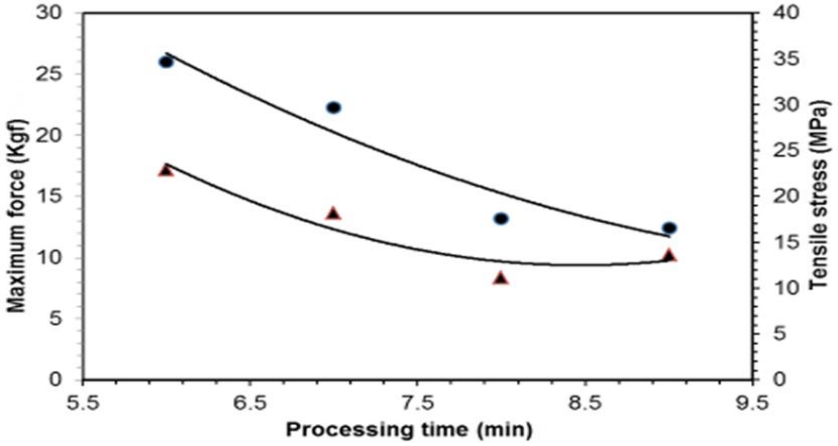

Fig. 2. Effect of different processing time on maximum force at yield point and tensile stress of the composite [●= maximum force; ▲= tensile stress]

It is important to obtain the optimum fiber content to achieve maximum property. The variation of maximum force and tensile stress as a function of polyamide fiber wt% is shown in Fig. 4. There was over 40% increase in the value of maximum force when fiber content increased to 12.29% revealing the maximum achieved force under the experimental conditions. Furthermore, the maximum tensile stress also recorded at this fiber content. Further increase of fiber weight percentage leads to drop in both of maximum force and tensile stress values. This suggests that these properties vary according to the role of mixtures and is basically dependent on the blend composition. This trend was not observed for the effect of processing temperature and time in addition to carbon content. The reasons for the increase of maximum force and tensile stress might be due to (1) the higher strength of the fiber which contribute in improvement of the composite properties, (2) formation of strong structure among all the other compositions, and (3) transfer the stress more easily to the fiber to reinforce the polypropylene [16]. The decrease in the values of maximum force and tensile stress maybe because of the presence of too much fiber within the body of the matrix which increased the probability of fiber agglomeration and led to explore regions of stress concentration that required less energy to slip the chains from each other. In addition to the discontinuity of polypropylene matrix, lowering the entanglement of chains caused the dropped of maximum force and tensile stress values [17].

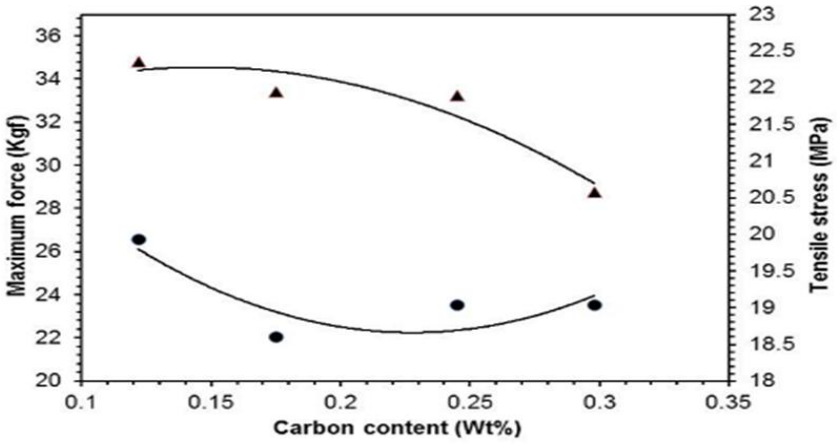

Fig. 3. Effect of different carbon black powder contents on maximum force at yield point and tensile stress of the composite [●= maximum force; ▲= tensile stress]

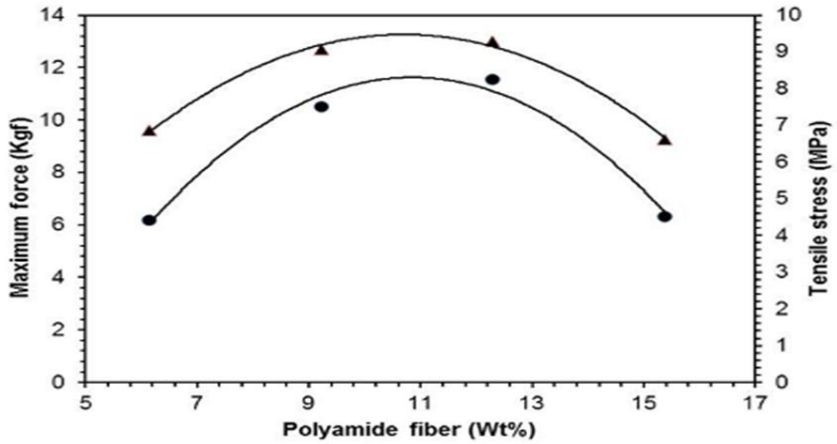

Fig. 4. Effect of different polyamide fiber contents on maximum force at yield point and tensile stress of the composite [●= maximum force; ▲= tensile stress]

Fig. 5 presents the variation in breaking force and elongation at break for the polymer composite produced under different processing temperatures at constant composition and processing time. It can be seen that the breaking force and elongation increase when the processing time is increased. The results of both breaking force and elongation are fitted to a linear relationship with R^2 equal to 0.93 and 0.96, respectively. The results elaborated that the breaking force raised about 30% at processing temperature of 200°C. Furthermore, the elongation at break increased to more than 60% when the processing temperature was increased from 170°C to 200°C. The increase in breaking force and elongation at break as a function of temperature at constant processing time could be attributed to increase in the mobility the polymer chains during heating and compression process, as a result, more chains entanglement occurred led to raise the breaking force and elongation.

The obtained dependences of break force and elongation at break on processing time of polypropylene composite at constant composition and 180°C processing temperature measured at ambient conditions are shown in Fig. 6. The collected data of breaking force and elongation at break are fitted to straight lines with regression factors of 0.93 and 0.96, respectively. Generally, there are high decrease in the breaking force values and moderated decrease in elongation at break values. The decrease in the breaking force and elongation of the composite as the processing time increased maybe have resulted from thermal degradation of the macromolecules as the composed maintained at 180°C for a relative high period of time during the sheets production.

The break force and elongation at break of polypropylene composite as a function of carbon black weight fraction (wt %) is shown in Fig. 7. The addition of the carbon powder to the composite exhibits a reduction in break force. A linear relationship with R-square of 0.97 was obtained when the recorded breaking force fitted to straight line. The force decreases slightly with the increase of the carbon content. Furthermore, the increase of carbon black content from 0.122% to 0.175% in the composite resulted in some moderate elongation at break property improvement (the optimum) from 2.51 mm to 8.50 mm elongation, respectively. The increase in elongation at break with increase of carbon content to 0.175% could be due to the incorporation of carbon powder particles between the polymer chains which may decrease the degree of crystallinity of polypropylene and increased the elongation [18]. Further increase of carbon content may cause the molecular mobility to decrease due to the extensive formation of physical bonds between the filler particles and the polymer chains that stiffen the matrix.

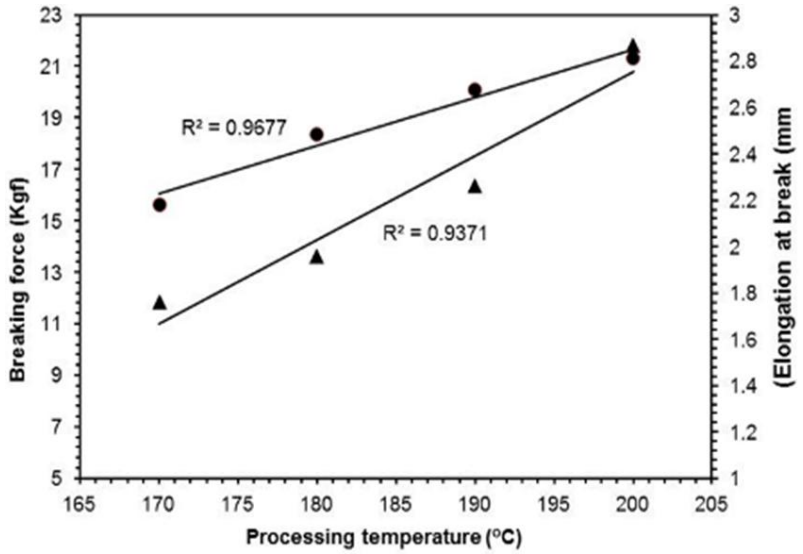

Fig. 5. Effect of different processing temperature on breaking force and elongation at break of the composite [●= breaking force; ▲= elongation at break]

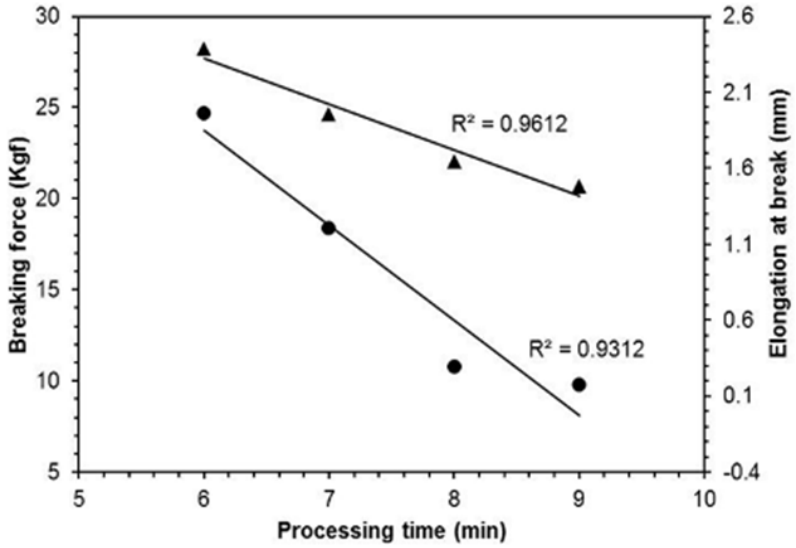

Fig. 6. Effect of different processing time on breaking force and elongation at break of the composite [●= breaking force; ▲= elongation at break]

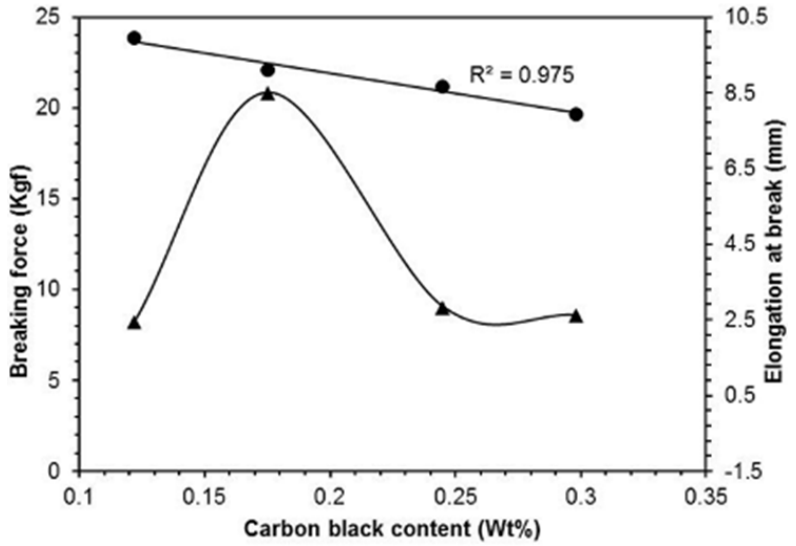

Fig. 7. Effect of different carbon black weight percentage on breaking force and elongation at break of the composite [●= breaking force; ▲= elongation at break]

The changes in breaking force and elongation at break of the composite sheets of different polyamide fiber contents at other constant parameters were observed by tensile testing as seen in Fig. 8. The addition of polyamide fiber to the polypropylene from 6.14% to 12.29% increases the break force followed by a decrease with further increase of the fiber wt%. The elongation at break showed increasing tendency up to 9.22 wt% of fiber loading and then decreased with increasing fiber load. The highest elongation property observed at around 9.22 wt% fiber and can be explained by increase in the chain mobility and decrease in the degree of crystallinity and, as a result, the elongation increased. The decrease in the value of elongation at break with further increase of fiber content can be explained by: (1) increase of fiber content in a constant volume may result in discontinuity of the macromolecules and (2) restriction of the mobility of the macromolecules in the matrix because of the interfacial adhesion between the composite compounds and form a relative rigid material.

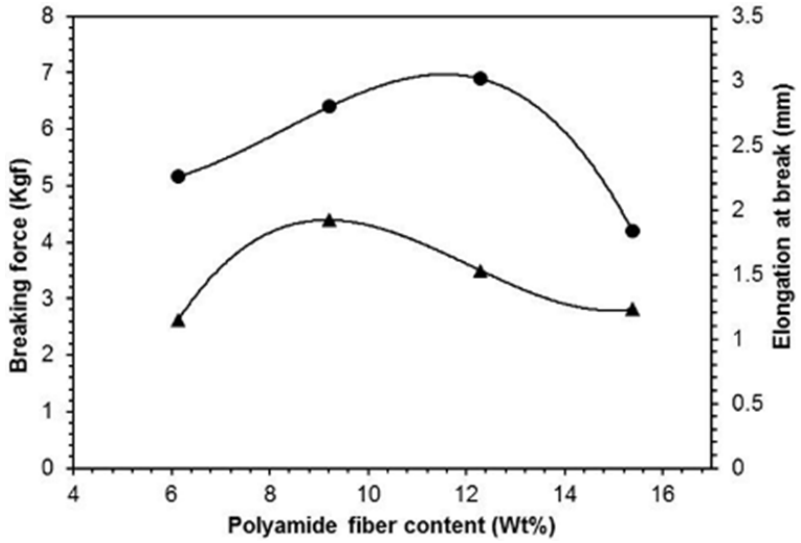

Fig. 8. Effect of different polyamide fiber weight percentage on breaking force and elongation at break of the composite [●= breaking force; ▲= elongation at break]

4. CONCLUSION

Tensile properties of polypropylene composite were study to evaluate the effects of processing temperature, processing time and carbon black powder and polyamide fiber contents. The obtained results concluded that the processing time and carbon black content have reversed impact on the investigated properties. The maximum force at yield point was achieved when polyamide content was 12.29% and increased with increased the processing temperature. The optimum polyamide wt% to obtain maximum tensile stress was 12.29%. The elongation at break increased with increasing the processing temperature and decreased with increasing the processing time. The maximum elongation at break was achieved when the percentages of carbon black and polyamide fiber were 0.175% and 9.22%, respectively.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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