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Tensile characteristics of chopped glass fiber reinforced polypropylene composites with different feed-stock lengths produced by injection molding

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ABSTRACT

Currently; Products fabricated from plastics represent a big marketplace proportion; especially thermoplastics which are the foremost part of this marketplace proportion. injection molding is the most common approach for producing thermoplastic where they could be shaped into molds. In this study; Polypropylene was reinforced using different weight fractions of chopped glass fibers. The composites of glass fiber reinforced polypropylene were produced using an injection molding machine. Polypropylene was mechanically mixed with glass fiber with different chopped lengths and weight fractions before injection molding then the resulting composites were smashed and re-injected for the sake of uniform fiber distribution. Burn-out tests were made to measure the actual weight fraction and the resulting fiber lengths. The results showed a decrease in the weight fraction accompanied by a massive decrease in fiber lengths. After performing a group of tensile tests on the specimens; the specimens' strengths were enhanced with the addition of chopped glass fibers and unfortunately, these enhancements vanished as extra chopped glass fibers were introduced. More air voids were observed in specimens with higher percentages of chopped glass fibers as scanning electron microscope micrographs and voids measurements showed. The air voids weakened the composite resulting in the reduction of tensile stress. The tensile strain of the specimens was reduced once chopped glass fibers were added to the neat polypropylene.

1. Introduction

Plastics are currently the best replacements for metals in different fields due to their high thermal and electrical resistivities, light weights, and high resistance to corrosion. Commercially worldwide; Thermoplastics cover the major part of the synthetic polymers' market [1]. Recycling ability and relatively lower costs for most thermoplastics favor their use over other polymers. Polypropylene (PP) can be recycled repeatedly without notable degradation and have a high strength-to-weight ratio [2]. PP could be produced either by injection molding or with other processing techniques however, injection molding is the most appropriate production technique for PP.

Several types of fibers have been used to reinforce polymeric-based composites including natural and

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synthetic fibers [3–6]. The effect of the GF addition to the polymeric matrix-based composites has been investigated in a big number of studies [6–10]. Also reinforcing PP with GF to enhance strength was investigated in several studies. Denault et al. [11] used ready GF/PP pellets with particular volume fractions (v_f %) and perform a dilution process to obtain a lower v_f %. At high fiber v_f %; higher ultimate strengths were obtained however fiber orientation was reduced in the mold. Bowyer and Bader [2] and Thomason [12] used PP with different GF v_f % prepared by injection molding using an end gate technique and found that as the v_f % of GF increases the strength of the composite increases. However, Thomason [12] noticed a decrease in the strength above 40 v_f % and the tensile strain was dropping all along. Also, the same study observes a linear increase in the young's modulus with reduced linearity at high percentages of v_f %.

Himani and Purnima [13] and Fu et al. [14] used twin-screw extruded GF/PP pellets with different contents of GF; where a little enhancement for the tensile strength was obtained as v_f % increased for the produced composite. Serrano et al. [15] and López et al. [16] mix GF and PP with the aid of a coupling agent before the injection process using an internal mixing machine and observed a significant increase in the tensile strength of GF/PP composites at higher fiber contents. Guo and Kethineni [17] used the direct fiber feeding injection molding method; where the tensile strength was noticed to be increasing as PP reinforced with GF. Additionally, Ota et al. [18] obtained a noteworthy elevation in tensile strength of GF/PP composites at a higher fiber weight fraction (wt.%) for injection molded composites.

A huge reduction in costs and waste generation reduction could be aided through the recycling of thermoplastics instead of using virgin raw materials [19, 20]. Abdelhaleem [21] manually mixed GF with Recycled PP in the hopper before injection molding and found that tensile strength increased with fiber content. AlMaadeed et al. [22] obtained the same as Abdelhaleem despite using a pre-manufactured GF/PP pellet from recycled PP. Kang et al. [20] injection-molded a hybrid of virgin GF/PP pellets plus 1-4 times recycled composites and concluded that more degradations take place to the tensile strength of the composites as more recycling performs.

The addition of GF to virgin PP and recycled PP is sufficiently investigated however, investigations of chopped glass fiber reinforced polypropylene (CGF/PP) composites produced by mechanically mixing CGF and PP before injection molding were not sufficiently covered. Some local plastic manufacturer attempts to use this technique to produce CGF/PP; hence more investigations on this technique are required.

2. Experimental

2.1. Materials

The Matrix material used here is a copolymer polypropylene (PP) supplied by SABIC®-Egypt of 0.905 g/cm³ density. PP pellets have a melt flow index (MFI) of 70 g/10 min at 230°C/ 2.16 kg. 12- and 24-mm lengths chopped strands of E-glass fibers (CGF) supplied by JUSHI were used as reinforcement material. Both material specifications are listed in Table 1.

Table 1 Properties of composite constituents

Material	Polypropylene		Glass fibers	
Type	Copolymer		E-glass fibers	
Properties	MFI	70 (g/10 min)	Length	12 and 24 mm
	Tensile strength	27.5 MPa	Diameter	13 µm
	Flexural modulus	1324 MPa	Tensile strength	2.5 GPa
	Density	0.905 g/cm	Young's modulus	73 GPa
			Density	2.55 g/cm

2.2. Composite fabrication:

A Manual mixing was made for PP pellets with different weight fractions (wt.%) of GF,10, 20 and 30 wt.%, in the hopper of the HAITIAN PL1200 injection molding machine. The injection molding process data was tabified in Table 2. The injection process was obtained for each wt.% with different fiber chopped lengths of 12- and 24-mm. The injection process was made in the following steps:

- After the mixture of PP and GF were mixed appropriately with specific wt.% and chopped length; the mixture was then interred to the machine extruder to be molded into stage 1 specimens.
- Stage 1 specimens for each wt.% and chopped length were then crushed along with sprues and runners to small pieces of 60 -100 mm2 in size.

- Crushed pieces were fed once again to the injection molding machine and re-injected into the required test samples.

The re-injection process was made to permit good distribution of CGF in the PP matrix. The whole injection process was illustrated in Fig. 1. More details about manufacturing process were provided in a previous study [23].

Table 2 Injection molding machine specifications

Model	HAITIAN PL1200				
Maximum clamping force	1200 kN				
Thermal zone	1	2	3	4	5
Barrel Temperatures (°C)	140	160	180	190	200

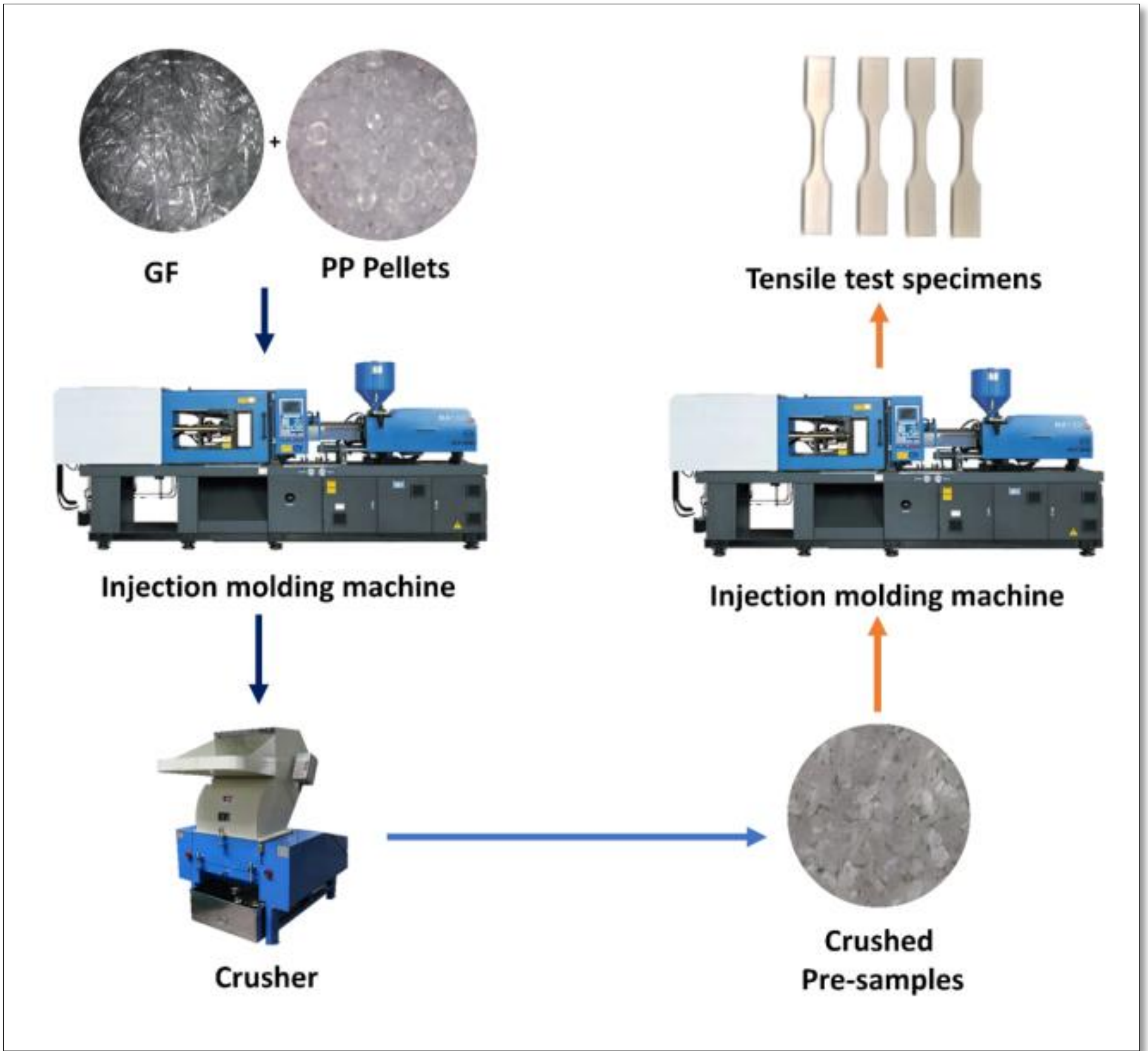

Fig. 1. Test specimens manufacturing cycle

Table 3. Specimens compositions and names

Specimen's name	PP (wt.%)	GF (wt.%)	Chopped length (mm)
T00	100	0	-
T1012	90	10	12
T2012	80	20	12
T3012	70	30	12
T1024	90	10	24
T2024	80	20	24
T3024	70	30	24

1.1. Mold characterizations

Tensile specimens were injected according to ASTM638 standard with specific dimensions as shown in Fig 2. The mold was designed according to standards including passages for cooling to facilitate the injection process and previously examined for quality and precision. The direction of injection was uniformed in a single direction to prevent melt-front from splitting within the mold which could generate weld lines.

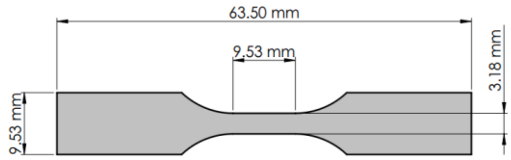

Fig. 2 Dimensions of the test sample

3. Results and discussion

3.1. Measurement of fiber weight fractions and fiber lengths

After the injection molding process, the weight fractions of glass fibers must be measured and may be affected due to material loss during the injection process. hence it is important to re-measure the weight fractions after the injection process in order to know the actual fiber weight fraction. A sample from the produced composites from each composition was burned out in a muffle furnace at 570°C for around 4 hours to permit the evaporation of the matrix. The remaining fibers are then weighted using Mettler AE200 after cooling down. the weighting results are illustrated in Fig 3.

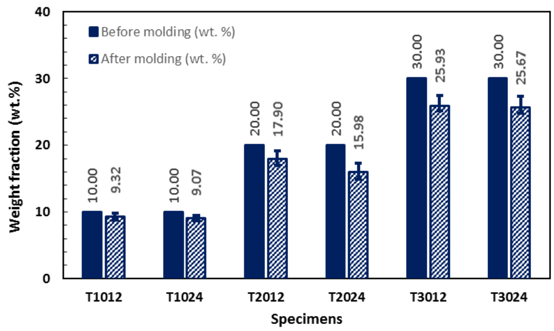

Fig. 3. Glass fiber weight fractions before and after the injection process

As shown in Fig 3, it has been clear that the weight fractions of glass fibers reduced after the injection molding process. Elevated reduction in glass fiber weight fractions occurs for specimens produced from longer feedstock fibers. The fibers' weight fraction reduction is related to the losses in materials during the injection process and also during the crushing process.

The remaining fibers were captured and then the fibers' lengths were measured from the captured photographs using ImageJ application. The average lengths of fibers could be indicated using two different formulas as mentioned previously in [24] & [25]:

$$L_n = \frac{\sum N_i L_i}{\sum N_i} \quad (1)$$

$$L_w = \frac{\sum N_i {L_i}^2}{\sum N_i L_i} \quad (2)$$

Where L_n is the number average fiber length, L_w is the weighted average fiber length, L_i is the length of the fiber i and N_i is the number of repetitions of the length of fiber i. L_w is influenced by the longer fibers presence. However, L_n is influenced by the repetition of fiber fragments. L_w is always have greater values than L_n [24, 25]. Figure 4 represents both L_w and L_n of the measured fiber lengths.

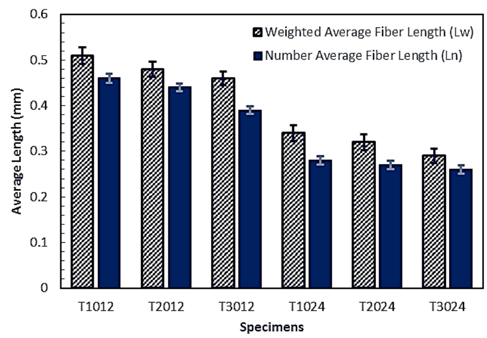

Fig. 4 Weighted and Number average lengths

Dramatic reduction in fiber lengths could be noticed after the injection molding process as shown in Fig 4. This reduction in fiber lengths is also noticed by previous investigations [14, 18, 20, 24–29]. The composite material is introduced to shear and compressive stresses in the barrel of the injection molding machine due to friction which severely raptures the fiber resulting in fiber length reduction [30]. The rapture occurred to the fibers in three steps firstly during the first injection process then the crushing process and then during the second injection process [20, 26, 29]. The resulting fiber lengths were also reduced as higher weight fractions were introduced to the composite, Fig. 4, as also concluded in previous studies [14, 18, 25–27, 30]. Histograms of the resulting fiber lengths were shown and discussed in a previous investigation [31].

L_w and L_n decreased when injecting longer fibers whereas injecting PP with 12 mm fibers has greater values for L_w and L_n than 24 mm fibers where the percentage of reductions in the fiber lengths for specimens produced from 24 mm and 12 mm fibers reach up to -98.92% and -96.75% of the initial length respectively. The possibility of fiber damage increased at increased fiber weight fractions due to elevated fiber interactions at higher weight fractions as observed by Kumar et al. [25]. Kumar et al found that, when injecting longer fibers, both L_n and L_w increased up to a 9 mm fiber length, while injecting fibers with longer lengths exceeding 9 mm resulting in reduction in both L_n and L_w. Due to this finding, the composites injected with 12 mm fibers will be called “LF/PP” and the composites injected with 24 mm fibers will be called “SF/PP”.

3.2. Measurements of void content and scanning electron microscope

All specimens’ dimensions were measured carefully using both caliper and micrometer with a dimension tolerance not exceeding $\pm 0.02\, mm$. The volumes of the specimens were then calculated from the measured dimensions and also the specimens were weighted using Mettler AE200. In order to measure the contents of the void, the following formula was used [32].

$$v_{voids} = 1 - \frac{\rho_{exp}}{\rho_{th}} \qquad (3)$$

Where v_{voids} is the percentage of voids in the material ρ_{exp} is the experimentally measured density of the material and ρ_{th} is the theoretical calculated density of the material.

Figure 5 represents the values of void contents in PP and CGF/PP. the percentages of air voids raised by 250% for LF/PP from T1012 to T3012 specimens and 270% times for SF/PP from T1024 to T3024. The increased values of air voids at higher fiber weight fractions may be related to the elevated values of fiber/Matrix interfaces in which the air voids exist.

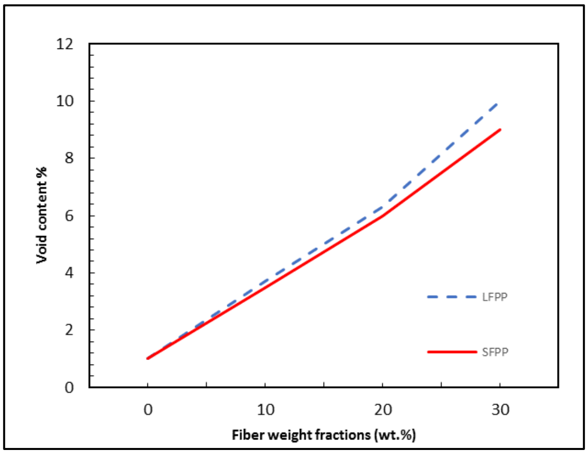

Fig. 5. The Void contents in PP and CGF/PP

The scanning electron microscope (SEM) micrographs of CGF/PP are shown in Fig 6 and 7. The micrographs clarify the existence of air voids between fibers and the matrix. It could be also noticed from Fig. 6 and 7, that the existence of air voids is higher in specimen T3012 than in specimen T1012 which has a higher concentration of fibers.

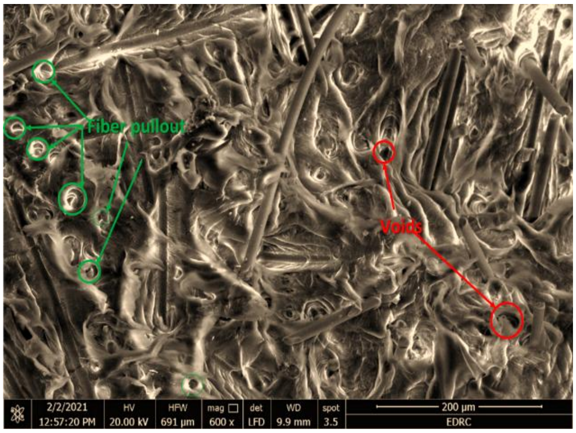

Fig. 6 SEM micrograph of specimens T1012

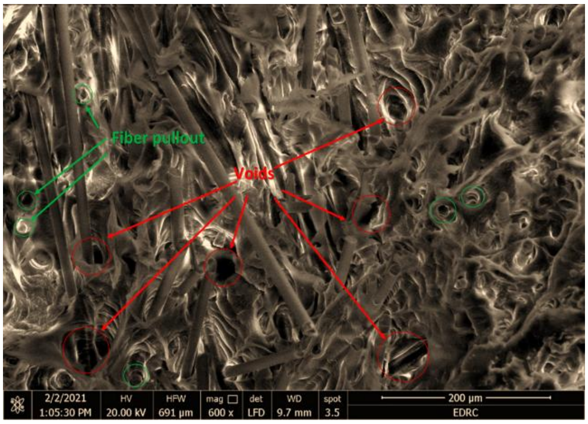

Fig. 7 SEM of micrograph specimens T3012

3.3. Tensile strength of PP and CGF/PP

According to the standard ASTM638, PP and CGF/PP were tested in tension. Each specimen with different composition was tested five times excluding any specimens that does not meet the standard specifications. The results of tensile tests including error bars were represented in Fig. 8 and 9. Figures 8 and 9 indicate that the composites including 10% glass fibers, by weight, have the best tensile strengths for both LF/PP and SF/PP. The values of tensile strengths for both LF/PP and SF/PP subjected a decrease when the wt.% of the fibers increased above 10%. From Fig. 8 and 9, LF/PP specimens seemed to have higher strengths than SF/PP specimens for similar weight fractions.

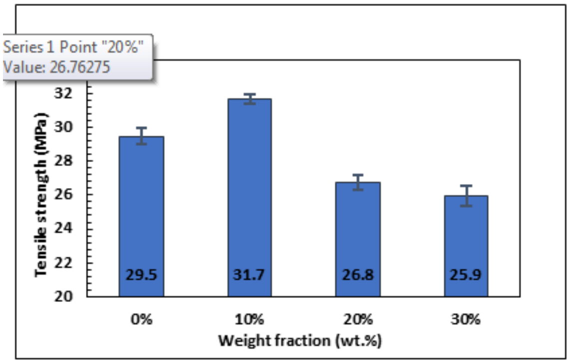

Fig. 8 Tensile strengths of neat PP and LF/PP

The LF/PP specimens have longer fibers than SF/PP which can explain the strength enhancement of LF/PP over SF/PP along with all specimen compositions.

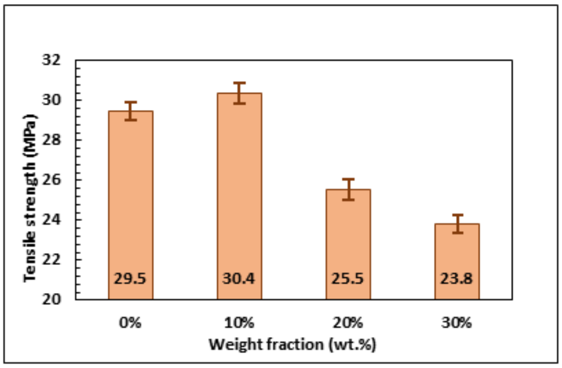

Fig. 9 Tensile strengths of neat PP and SF/PP

The glass fiber addition slightly elevates the tensile strength of the composite attributable to the higher values of the glass fibers' tensile strength than PP. The extra addition of glass fibers reduces the composite tensile strength because of higher concentrations of air voids at higher percentages of fibers as previously explained in both Fig. 5 and Fig. 6. The Air voids existence overcomes the increase of composite strength through the addition of strong glass fibers as mentioned by Hagstrand et al. [32].

The air voids may also be elevated due to repeating the injection process with big and irregular granule sizes which may not be favored in the injection process. Irregular pellets sizes can completely/partially unmelt some pellets and hence an internally defected part may result [33].

The connection between composite strength and mean fiber length was investigated beforehand by Kumar et al. [25] and Subramanian et al. [24]. They concluded that the composite tensile strength improved at longer mean fiber lengths. Kumar et al. [25] additionally found that the impact of the increase in mean fiber length on the composite tensile strength is greater than the impact of higher fiber content where the drop in composite strength because of low fiber content could be enhanced by elevating the mean fiber length.

3.4. Tensile strain and fracture mechanisms

Figure 10 represents the tensile strain of neat PP and CGF/PP composites for LF/PP and SF/ PP as obtained from the tensile testing machine. A drop was observed in the tensile strain of all CGF/PP specimens than neat PP having a percentage of reduction exceeding -84 % at 10 wt.% and up to -93% at 30 wt.% of the neat PP strain. the reduction in strain increases as more weight fractions of glass fibers are added. Nearly similar results were obtained from both LF/PP and SF/PP where the strain values were irrespectively affected by the resulting fiber length.

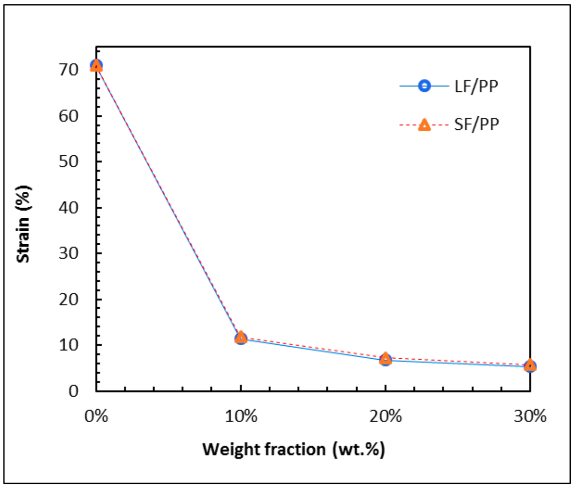

Fig. 10. The tensile strain of PP and CGF/PP for both LF/PP and SF/PP

The specimens have been captured after tensile tests and the photographs are shown in Fig. 11. the best elongation was obtained from neat PP specimens T00 where the test specimens remain un-fractured after the tensile test which agrees with the value of the tensile strain. Once the glass fibers were introduced to the PP matrix the specimens fractured and a huge drop in the specimen elongation was observed which also agrees with the values of specimens' strains shown in Fig. 10.

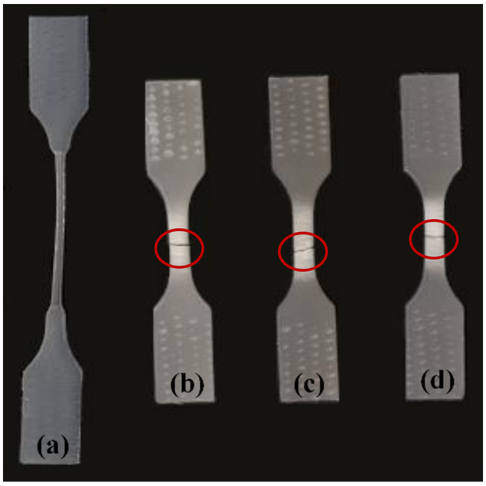

Fig. 11. Tensile specimens after tests; (a) T00, (b) T1024, (c) T2024 & (d) T3024

3.5. Modulus of elasticity (E)

The moduli of elasticity were measured from the slope of the 0.2% linear line in the elastic region of stress-strain curves for each specimen composition and then plotted in Fig. 12. It is observed from the figure that the elastic modulus was improved by the addition of glass fibers where a percentage of improvement starting from 140% and 128% for T1012 and T1024 to 247 and 228% for T3012 and T3024 respectively over T00. Elastic moduli of LF/PP composites are higher than that of SF/PP composites due to the longer lengths of the glass fibers in the resulting composites.

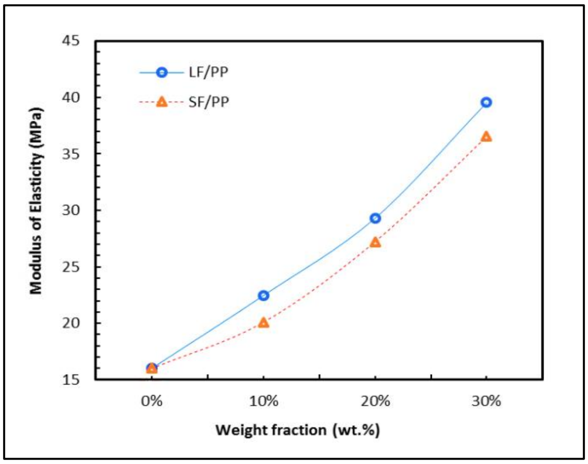

Fig. 12 Modulus of elasticity for PP and CGF/PP composites

4. Conclusions and recommendations

The tensile behavior of injection molded CGF/PP with different wt.% and initial lengths using mechanically mixed CGF and PP was investigated in the current study and the findings could be concluded to:

- The wt.% were found to be reduced up to 4 % after injection molding due to in-process material losses.
- The resulting fiber lengths were hugely reduced by over 98% of the initial length, and the percentage of reduction increased as weight fractions increased.
- The specimens made of longer chopped fiber lengths were noticed to have shorter fibers in the resulting composite.
- The tensile strength increased slightly when 10

wt.% of fibers add however increasing fiber wt.% more than 10 wt.% drops the strength of the composite because of the increased percentages of air gaps generated in fiber/matrix interfaces which increased as more fibers exist.

- A significant reduction in strain along with rapid fracture was noticed with percentages up to -93% of the original strain of neat PP which remains un-fractured. The modulus of elasticity improved by the addition of glass fibers and increased as fiber weight fractions increased.

The currently used producing technique may be related to the poor tensile properties of CGF/PP where previous investigations obtained more decent tensile properties from CGF/PP. Afterward, the current producing technique is not recommended for applications that require high tensile properties.

It is suggested to use a coupling agent which may reduce the formation of voids in the composite and enhance the properties. Also using smaller initial fiber lengths than 12 mm could result in higher fiber lengths in the resulting composite which may positively affect the composite properties.

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