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Effect of Reinforced Glass Fibre on the Mechanical Properties of Polyamide

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Abstract. The aim of this study is to enhance the tensile and flexural strength of polyamide (nylon 6, 6) by incorporation of glass fibre. Nylon has high elasticity, strength, toughness and maintain mechanical properties at elevated temperatures. The method employed for enhancement of properties is by the reinforcement of glass fibre. Glass fibre is the most extensively used reinforcement material. It is a lightweight, extremely solid, durable, low cost material that moderafly stiff. The composition of glass fibre was kept at 0 wt.%, 30 wt.% and 50 wt.% in nylon 6,6 blend. Initially, samples were manufactured by injection molding of nylon 6,6 and glass fibre. The pressure and velocity profiles at 0 wt.%, 30 wt.% and 50 wt.% reinforced nylon 6,6 are also compared. The samples thus formed were checked for shrinkage. The samples were tested for their tensile and flexural properties. The mechanical properties of polyamide (nylon 6,6) significantly improves by increasing glass fibre reinforcement.

Keywords: flexural strength, glass fibre, nylon 6,6, polyamide, tensile

Introduction

The term nylon is a conventional term used to describe a category of synthetic polyamides that are synthetic. The amide group (– CONH–) in nylons forms some portion of the polymer fundamental chain. The chemical structure of nylons are divided into two categories, one based on dibasic acids or diamines and other based on lactams or amino acids. Nylons are referred by a numbering system that reveals the number of carbon atoms in their structure, like nylon 6 represents polycaprolactam (poly. ω-amino caproic acid). In the nylons family, nylon 6 and nylon 6.6 are of the utmost commercial importance as they offer good set of properties with economical cost. Other commercially useful materials like, e.g are nylon 6,9; nylon 6,10; nylon 6,12; nylon 11; and nylon 12, have relatively higher prices (Pickering *et al*., 2016).

Nylon 6 and nylon 6,6 have semi-crystalline structure with good durability and strength for challenging applications with their own distinct and separate benefits they do share some core properties such as good fatigue resistance, electrical insulating properties, sliding properties, resistance to high energy radiation, machinability and excellent wear resistance. It also has high mechanical damping ability, mechanical strength, stiffness, hardness and toughness (Pickering *et al*., 2016; Teixeira *et al*., 2015).

Althow nylon 6 and nylon 6.6 are very alike materials they also possess some different characteristics, these differences are due to different chemical structure. The nylon 6 consist of one monomer with 6 carbon atoms, while nylon 6,6 has 2 monomers with each one having 6 carbon atoms, therefore named as nylon 6,6 (Saba *et al*., 2014). Table 1 shows the comparison of different properties of nylon 6 and nylon 6,6. Also, nylon 6 endures high impact stress and stands up to hydrocarbons well while nylon 6,6 has improved stiffness, tensile and flexural modulus. Nylon 6,6 is a very common engineering thermo plastic used in plastic processing. Nylon 6,6 can be used with a different composition according to the requirement of the product. It shows very high flow in thin sections and has good weld

Table 1. Comparison of different properties of nylon 6 and nylon 6,6

Properties	Nylon 6	Nylon 6,6
Crystallinity	Less	More
Mold shrinkage	Lower	Higher
Melting point	Lower	Higher
Heat deflection temperature	Lower	Higher
Water absorption rate	High	Lower
Chemical resistance	Poor	Better

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strength. It is a hygroscopic compound and pre-drying is important. The crystalline melting point of nylon is 265 °C. It shows very high resistance towards wear because of its very high molecular weight. The major application of nylon includes nylon fibre, clothing, footwear, panty house, tooth brush bristles, finishing lines, air bag fibre, parachutes machine parts such as gears and bearing (Frihi *et al*., 2016).

The aim of this study is to use reinforced nylon 6,6 with 0 wt.%, 30 wt.% and 50 wt.% glass fibre and injection molding and to identify the difference in pressure and velocity profile, when used with three different glass fibre reinforcements by a graphical representation. In addition, the shrinkage factors, tensile strength, elongation modulus, elongation at break, flexural stress, flexural strain and flexural modulus for all the three reinforcements of glass fibre, will be discussed.

Materials and Methods

Polyamide and Nylon 6, 6 glass fiber reinforcments (toughness, low coefficient of friction, and good abrasion resistance) were purchased from Merck, Germany.

Injection molding. Injection molding is very common and popular in plastic processing techniques, in which molten material is injected into the cavity, allowing the material to cool down and solidify and eject the material. There are many ejection systems used to eject the material like pin ejection, sleeve ejection, air ejection, which depending upon the nature of the product and mold. Normally the injection molding machine is divided into two parts provided with the mold between injection and clamping unit (Nagakura *et al*., 2017). The injection unit consists of a screw motor, a barrel, a hopper, a heater band, a stationary plate and aninjection nozzle. The Barrel plays a vital role in the method of injection moulding process. It is also called the heating cylinder. Normally, it is made of an inexpensive grade of steel. The barrel is supported by an electrically activated heater band. Normally, the barrel is divided into three zones, unusual centre and front. The temperature is comparatively low in the rare zone and increasing consistently in the centre and front zone. The injection screw is placed inside the barrel. Screw design is very important in polymer processing and it may vary from material to material. The hopper is the component, where the plastic material is initially stored before it is injet to the barrel, its size depends on the machine size. Sometimes hopper is supported by dryer for drying of the material which is hygroscopic. The nozzle is the final component of the injection unit. The molten plastic is injected into the mold cavity with the help of a nozzle. A heater band is provided at the nozzle tip known as nozzle heater (Nagakura *et al*., 2017). The basic purpose of the clamping unit is to grip the mold throughout the injection process. The pressure in the clamping unit should be equal to the injection unit. The clamping unit normally has three types of systems, toggle or mechanical, hydraulic and third is the combination of mechanical and hydraulic clamping (Pickering *et al*., 2016).

Parameters of the injection molding process. In injection molding different parameters affect the product quality. Main processing parameters of the injection molding, process are temperature, pressure, time and distance. The variation in the temperature affects the injection molding process and the quality of the final product. It may include the melt temperature, mold temperature and even the ambient temperature. The melt temperature is normally maintained throughout the flow path, which starts from the hopper to machine barrel, then from machine barrel to nozzle. From the nozzle, it is injected into the mold cavity. The heating barrel has three zones, rear zone, centre zone and front zone. The temperature is gradually increases from the rear zone to front zone. The control of melt temperature is very important. The melting temperature of nylon 6 is 215 °C to 220 °C and nylon 6, 6 is 274 °C to 280 °C. After melting in the barrel, the material is now ready to flow into the mold, where the material will cool down. The cooling rate depends upon the material and the design of the product. The mold temperature of nylon 6 is 93 °C and nylon 6,6 is 79 °C (Essabir *et al*., 2018; Saba *et al*., 2014). Injection molding machines comprise of two units, injection and clamping unit. Both the two units require pressure and pressure control. The pressure in the clamp unit is required to overcome the pressure of the injection unit. There are three basic types of pressures in the injection unit, which are the initial injection, holding and backup pressures. The initial pressure is used to push the molten plastic. It is normally operated by hydraulic pressure. As a result of this pressure, the initial filling of the mold takes place. The holding pressure is also called secondary pressure, it is used with molten plastic for the final filling of the mold and holds it till the molten plastic solidifies. Shrinkage factor has been reduced by holding pressure.

Holding pressure is used to finish the filling of the mold. After the holding pressure, the back pressure is applied to the machine. Usually, the back pressure is small as compared to injection pressure. The back pressure is used to control the part weight, density and product appearance. During the injection process in the clamping unit, pressure is used to close the mold. The amount of injection and clamp force must be equal (Palazzetti, 2015).

Injection molding of nylon 6, 6. In the lab, the nylon 6,6 is used for experimental work and for the processing in injection moulding machine to make the test specimen for the tensile and flexural test. Nylon 6, 6 is taken with three different reinforcements of glass fibre that is nylon 6,6 with o wt.% glass fibres. Nylon 6,6 with 30 wt.% glass fibre and nylon 6,6 with 50 wt.% glass fibre. Table 2 shows the injection molding process parameters.

Shrinkage calculations. Shrinkage is calculated for tensile and flexural bar produced specimens by taking the difference of mold dimensions and specimen dimensions. The dimension of the mold cavity is measured by micro meter screw gauge when the width is 10.05 mm and thickness 2.39 mm for tensile bar and width is 10.06 mm and thickness is 4.03 mm, for flexural bar.

Tensile testing. The tensile test is a mechanical test of the material in which the behaviour of a material is determined under uni axial stretch loading. The elongation, elastic modulus, tensile strength and yield strength and other properties can be measured by using the data of the test. It is a quiet simple test to get a good tensile profile. The point of failure is normally referred to as ultimate strength. The stress σ (have been calculated by eq. (1). Figure 1 represents the specimens used for tensile testing manufactured on injection molding.

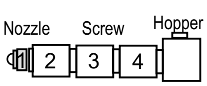
$$\sigma = \frac{\text{Load}}{\text{Cross – sectional area}} \quad \ldots\ldots\ldots\ldots \quad 1$$

The ratio of stress and strain is called Hook's Law, which is normally constant and determined by eq. (2).

$$E = \frac{\text{Strees } (\sigma)}{\text{Streain } (\epsilon)} \quad \ldots\ldots\ldots\ldots \quad 2$$

When the stress is proportional to strain, then it is called modulus of elasticity. The stiffness of the material is measured by the modulus of elasticity. It is the linear region of the curve. At this point, some permanent deformation starts to occur in the specimen. This point is normally referred to as proportional limit. At this point when the stress is removed, the material will not come to its original position. The 30 different samples have been tested for tensile properties. In these 30 samples, 10 samples are reinforced with 0 wt. % glass fibre, 10 samples with 30 wt. % glass fibre reinforcement and remaining 10 are 50 wt. % reinforced with glass fibre as shown in Table 3. All these specimens are manufactured on injection molding.

Table 2. Process parameters for injection moulding

Parameters	Units	Zone	0 wt.%	30 wt.%	50 wt.%
Barrel temperature (°C)	°C	1	310	310	310
		2	295	295	295
		3	295	295	295
		4	280	280	280
Mold temperature	°C	-	93	93	93
Shot size	mm		36.0	36.75	38.5
Injection velocity	mm/s		45	45	45
Transfer position	mm		10	10	10
Packing pressure	bar		375	375	375
Packing time	sec		19	19	19
Decompression distance	mm		3	3	3
Plasticization screw speed rpm			75	75	75
Plasticization back pressure	bar		50	50	50
Cooling time	sec		15	15	15

Flexural testing. The ability of a material to withstand bending forces applied perpendicular to its longitudinal axisis known as flexural strength. Flexural strength is

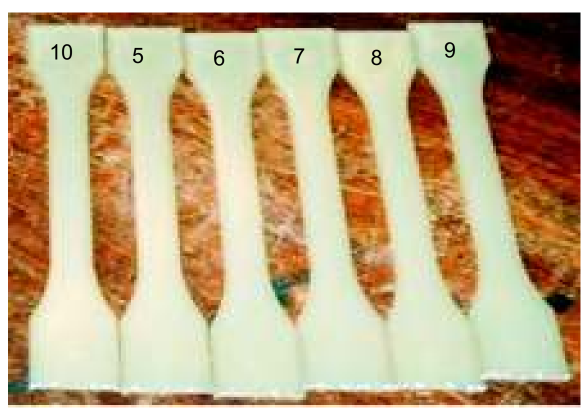


Fig. 1. Specimens used for tensile testing manufactured on injection molding.

Table 3. Tensile test data for 0 wt.%, 30 wt.% and 50 wt.% glass fibre reinforcement

Sample	Glass fibre	Time 'sec' wt.%	Load 'N'	Stroke 'mm'
1	0	34929.11	1018.36	2.879
2		151730.5	1441.056	12.61
3		135479.8	1428.059	11.263
4		138029.9	1424.617	11.476
5		122529.7	1428.608	10.179
6		35079.11	1011.957	2.891
7		115629.8	1384.97	9.609
8		120380.5	1418.92	10.005
9		150079.9	1450.82	12.483
10		28029.25	2453.26	2.309
11	30	28029.25	2453.26	2.309
12		26829.21	2430.266	2.209
13		27929.24	2473.81	2.3
14		34899.34	2401.206	2.879
15		30428.97	2476.67	2.504
16		31130.45	2045.78	2.563
17		29629.26	2473.58	2.443
18		30732.06	2437.1	2.53
19		35099.34	2253.21	2.89
20		29829.29	2381.32	2.459
21	50	29799.22	3511.43	2.454
22		29479.28	3446.68	2.430
23		34979.4	318.82	2.888
24		29401.51	3411.74	2.421
25		32129.34	3398.74	2.651
26		30428.97	3321.25	2.504
27		30529.31	3363.39	2.571
28		31198.93	3374.27	2.566
29		34429.09	3270.99	2.837
30		27780.68	3400.44	2.288

the combination of different stresses which include tensile stresses and compressive stresses. The calculation of flexural properties is done regarding stress and strain. Many polymers do not break, while testing flexural properties because it is a bending test and deflection is observed in these kinds of test. Three-point bending and four-point bending methods are used to determine the flexural properties. Normally the three-point bending method is used for the material which shows small deflection and four-point bending methods is used for the material which shows larger deflection during testing. In the flexural test the maximum stress can be obtained by the eq.(3) (Withers *et al*., 2015).

$$\text{Flexural stress} = \frac{3PL}{2w\,T^2} \quad \text{.....................................} \; 3$$

where:

'P' denotes the load, 'L' represents length of span, 'w' indicate the width of the specimen and 'T' for the thickness of the specimen. The flexural strain is calculated by the eq. (4).

$$\text{Flexural strain} = \frac{6DP}{L^2} \quad \text{..} \; 4$$

where:

'D' is the deflection, 'T' is the thickness of the specimen and 'L' is the length of the span.

While, doing the flexural test, specimen preparation, temperature and test conditions may affect the test results. It is also called flexural modulus that measures the stiffness of material during the first bending process as given in eq. (5) (Chaichanawong *et al*., 2016). The procedure for calculating the flexural modulus is quite

Table 4. Flexural test data for 0 wt.%, 30 wt.% and 50 wt.% glass fibre reinforcement

Sample	Glass fibre wt.%	Time 'sec'	Load 'N'	Stroke 'mm'
31	0	35229.4	8.25267	2.91058
32		32381.41	8.22894	2.6735
33		31229.32	7.86097	2.57932
34		30581.1	8.25847	2.52349
35		30879.35	8.269	2.54832
36		30899.25	7.355	2.54829
37		30629.31	7.95389	2.52766
38		30679.31	7.44169	2.53162
39		30979.32	7.51479	2.55683
40		36749.37	8.63706	3.03536
41	30	31079.32	26.2042	2.56495
42		36680.14	31.9799	3.03193
43		30799.25	26.1726	2.53953
44		30979.32	26.148	2.55662
45		30680.81	26.8317	2.53116
46		31279.33	27.0856	2.5814
47		30648.91	25.62	2.52244
48		30978.87	26.632	2.55164
49		30678.98	25.2232	2.52682
50		30978.99	25.5128	2.55161
51	50	31069.19	46.0038	2.56078
52		31579.56	47.7945	2.60606
53		20828.85	32.1127	3.36771
54		30599.24	45.4467	2.52328
55		30749.25	45.6067	2.53599
56		30728.98	45.6265	2.53078
57		31059.39	46.5317	2.56432
58		30979.32	46.2518	2.55662
59		30929.32	46.7502	2.55203
60		30928.99	45.7217	2.54744

similar to the procedure of calculating tensile modulus. In many cases values of flexural modulus and tensile modulus are same. The 10 samples of Nylon 6,6 with glass fibre reinforcement of 0 wt.%, 30 wt.% and 50 wt.% were used for flexural testing. All these test bars were manufactured on injection molding. Table 4 represents the flexural test data for 0 wt.%, 30 wt.% and 50 wt.% glass fibre reinforcement.

$$\text{Flexural modulus} = \frac{\text{Flexural stress}}{\text{Flexural strain}} \quad \text{.................... 5}$$

Results and Discussion

Pressure-velocity profile. According to the data provided for processing of nylon 6,6 it looks quite similar as shown in Table 2 for all the three materials, but certain differences changes have been observed in pressure velocity profile, which is shown in Fig. 2.

When nylon 6,6 is used with 0 wt.% glass fibre reinforcement, the initial injection pressure is not very high. That means low injection pressure is required to fill the mold cavity initially, then the pressure drops and constant holding pressure is applied to the mold. When the nylon is used with 30 wt.% glass fibre reinforcement, the initial injection pressure is quite higher as compared to the pressure that was observed in the processing of nylon 6,6 with 0 wt.% glass fibre reinforcement. However, the holding pressure looks constant for both the material but a wide difference has been observed between the initial injection pressure and holding pressure. When nylon 6,6 is used with 50 wt.% glass fibre reinforcement the initial injection pressure is relatively very high as compare to 0 wt.% and 30 wt.% glass fibre reinforcement. It was observed that increasing % glass fibre reinforcement would increase the initial pressure for pushing molten plastic to the mold cavity. This is because the melt viscosity will gradually increase due to the higher crystallinity in nylon 6,6 structure as two monomers contain 6 carbon atoms for each. The findings are accordance with the previous literature (Garcia *et al*., 2018; Fernandes *et al*., 2017; Bernasconi *et al*., 2015).

Shrinkage for tensile and flexural bar. Figures 3 and 4 representing the results for both tensile and flexural bars revealed that, the % of shrinkage increases with the increase is glass fibre reinforcement in both the direction that is in width and thickness. The mould

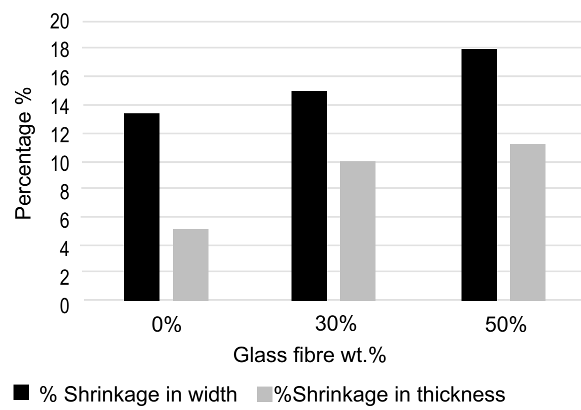


Fig. 3. Comparison between the percentage of shrinkage in width and thickness for the specimens of the tensile test.

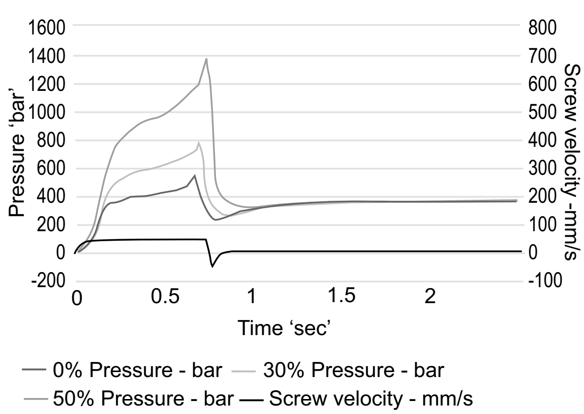


Fig. 2. Pressure-velocity profile comparison of nylon 6,6 with 0 wt.%,30 wt.% and 50 wt.% glass fibre reinforcement.

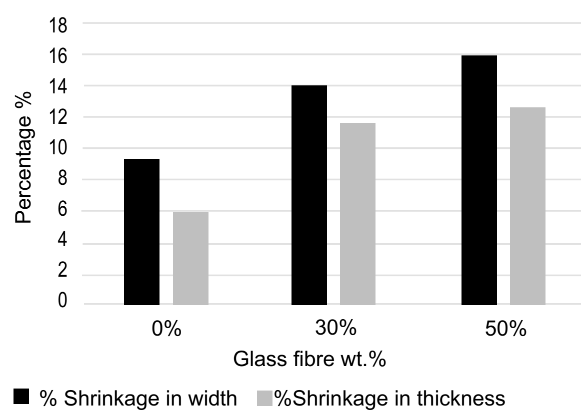


Fig. 4. Comparison between percentage shrinkage in width and thickness for the specimens of flexural test.

shrinkage of nylon 6,6 is further incresed by the re-bonding of glass fibre during the injection process and bonding strength has been increased. Table 5 is the summarized form of shrinkage results for tensile and flexural bar specimen with 0 wt. %, 30 wt. %, 50 wt. % glass fibre reinforcement. The present research work traced by the previous work.

The mechanical property of glass fibre filled polyamide composites are directed by the distinct properties of the fibre and blend, along with a multifaceted incorporation of some parameters such as fibre size, content, distribution and orientation, as well as physicochemical collaborations at the polymer-fiber interface (Graupner *et al*., 2016; Arif *et al*., 2014; Feldmann and Bledzki, 2014).

Tensile result of glass fibre reinforcement. Figure 5 represents the specimen of Nylon 6,6 with 0 wt.%, 30 wt.% and 50 wt.% glass fibre reinforcement after tensile testing. The obtained results revealed that with increasing the amount of glass fibre the tensile strength and elastic modulus is increasing significantly, whereas % elongation is decreasing as shown in Fig. 6 to 8. This means increasing the amount of glass fibre, increases the strength of the final product. The tensile test results for 0 wt.%, 30 wt.%, and 50 wt.% glass fibre reinforcement are shown in Table 6.

Table 5. Shrinkage results for tensile and flexural bar specimen with 0 wt. %, 30 wt. % and 50 wt. % glass fibre reinforcement

Shrinkage calculation	Glass fibre wt. %	Width 'mm'	Thickness 'mm'	% Shrinkage in width	% Shrinkage in thickness
Tensile bar	0	9.914	2.34	13.6	5
	30	9.90	2.29	15	10
	50	9.87	2.279	18	11.1
Flexural bar	0	9.967	3.971	9.3	5.9
	30	9.92	3.914	14	11.6
	50	9.903	9.903	15.7	12.6

According to the literature percentage elongation decreases due to rigid fibres restrain matrix deformation persuading strength gain and brittleness of the resultant

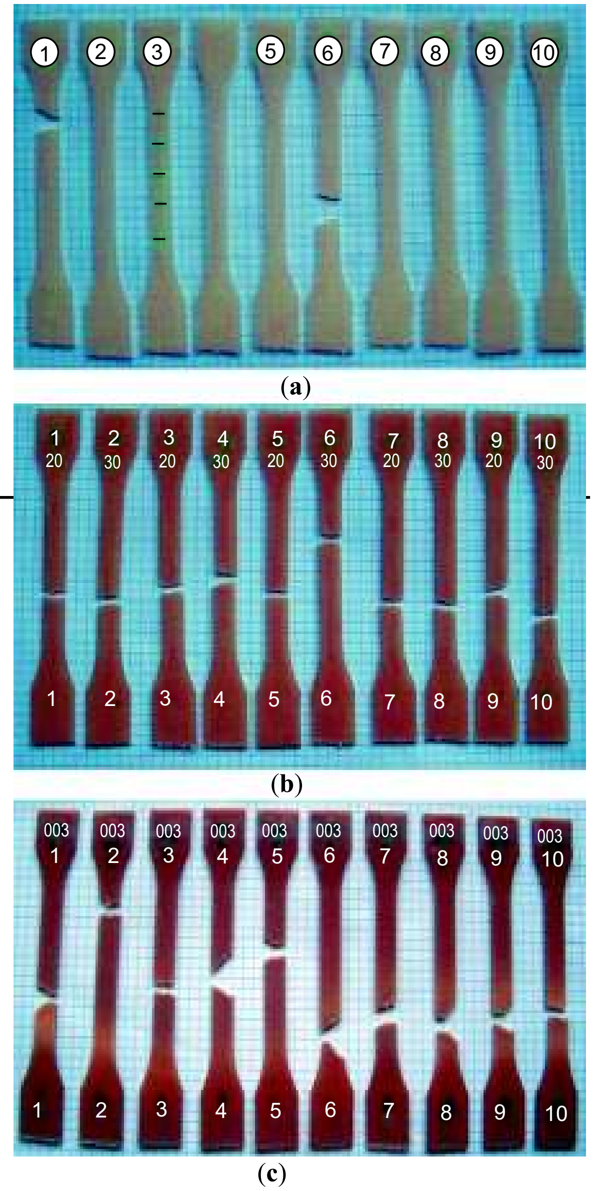


Fig. 5. Specimen of nylon 6, 6 with (**a**) 0 wt.%, (**b**) 30 wt.% and (**c**) 50 wt.% glass fibre reinforcement after tensile test.

Table 6. Tensile test results for 0 wt.%, 30 wt.% and 50 wt.% glass fibre reinforcement

Glass fibre reinforcement wt. %	Load 'P' N	Width 'w' m	Thickness 'T' m	Tensile strength M. Pa	Strain	%Elongation	Elastic modulus G. Pa
0	1450.82	0.009914	0.00234	62.53	0.24966	24.966	0.250
30	2401.20	0.00990	0.00229	105.915	0.05758	5.758	1.839
50	3411.74	0.00987	0.002279	151.68	0.04842	4.842	3.132

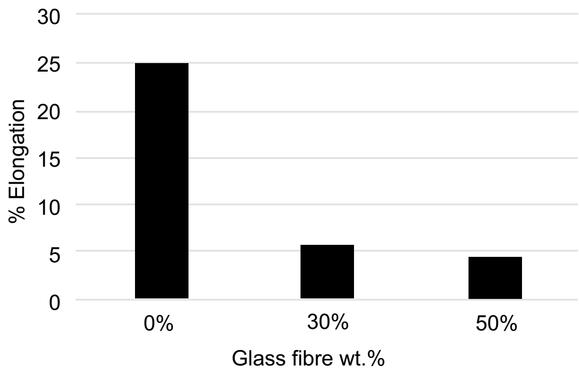


Fig. 6. Effect of % elongation for three sample of nylon with different wt. % reinforcement of glass fibre.

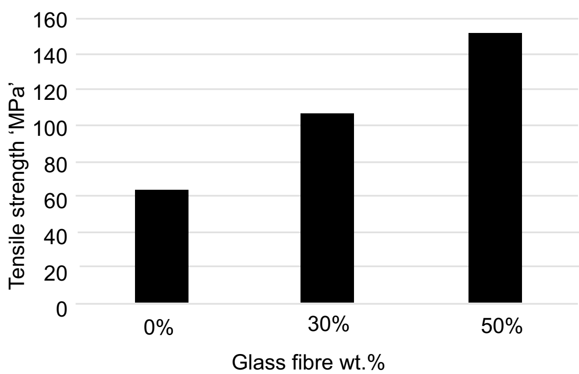


Fig. 7. Effect of tensile strength for three sample of nylon with different wt. % reinforcement of glass fibre.

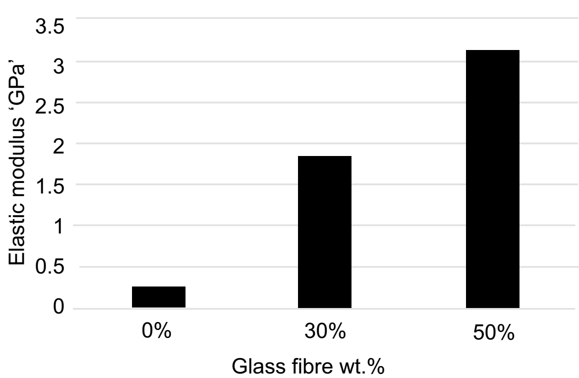


Fig. 8. Effect of elastic modulus for three sample of nylon with different wt. % reinforcement of glass fibre.

composites. Usually in polymer composites, glass fibres are used to increases the tensile properties. Numerous studies about glass fibre reinforced polymers have reported that increasing composition of glass fibre in the matrix (nylon 6,6), interfacial interactions leads to better load transfer. On the whole, the absence of agglomeration shows good affinity among the glass fibre and the nylon 6,6, that indicates good manufacturing conditions were used (Graupner *et al*., 2016; Ning *et al*., 2015; Sethi and Ray, 2015).

The nylon 6,6 with 50 wt.% glass fibre reinforcement represent high tensile strengths and elastic modulus. The highest value of strength and modulus were perceived for the glass fibre composites, attributable to higher strength, stiffness, better interfacial bonding of glass fibre (Basso *et al*., 2019; Mortazavian and Fatemi, 2015).

Flexural result of glass fibre reinforcement. Figure 9 shows that as the amount of glass fibre increases in nylon 6,6, the value of flexural modulus increases. When nylon 6,6 is used with 0 wt.% glass fibre reinforcement, the value for flexural modulus is very low, but it increases significantly. It means that stiffness of the material increases with the increase in glass fibre. Table 7, represents the summarized form of flexural test results for 0 wt.%, 30 wt.%, and 50 wt.% glass fibre reinforcement.

The reinforcement of glass fibre in the nylon 6,6 led to a change in mechanical properties also depending on the temperature and running conditions. This is anticipated as a result of the high modulus of glass fibre. However, all the results proved that nylon 6,6 make the interactions amongst the components stronger and this is proved by the solid-like behaviour of the composite at higher composition of glass fibre. The

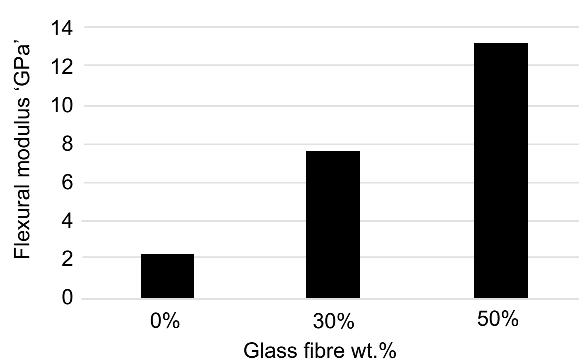


Fig. 9. Effect of flexural modulus on three sample of nylon with different wt. % reinforcement of glass fibre

Table 7. Flexural test results for 0 wt.%, 30 wt.% and 50 wt.% glass fibre reinforcement

Glass fiber reinforcement wt. %	Load 'P' N	Width 'w' m	Thickness 'T' m	Length 'L' m	Flexural stress M. Pa	Flexural strain	Flexural modulus M. Pa
0	8.25847	0.00996	0.00397	0.12	9.46	0.00417	2268.58
30	26.1726	0.00992	0.00389	0.12	31.384	0.004116	7624.59
50	45.7217	0.00991	0.0039	0.12	54.599	0.004139	13189.47

results obtained are in good agreement with previous literature concerning fiber reinforced composite (Garcia *et al*., 2018; Nagakura *et al*., 2017; Mortazavian and Fatemi, 2015).

Conclusion

In this study shrinkage calculations gave an approximate result that shrinkage regarding width and thickness increases from 0 wt. % to 50 wt.% samples. It was found that as percentage reinforcement increases percentage shrinkage increases at a lesser rate. The penultimate tensile test and its succeeding calculations declared that the tensile strength and elastic modulus significantly increased from 0 wt.% to 50 wt.% samples, whereas percentage elongation decrease. Synonymously, the concluding flexural test and its succeeding calculations showed a significant increase in flexural strength and flexural modulus from 0 wt.% to 50 wt.% glass fibre reinforced polyamide samples. Hence, it was concluded that mechanical properties of polyamide (nylon 6,6) significantly improve by increasing glass fibre reinforcement. The future recommendation is, shrinkage can be lowered by varying packing or holding pressure to changing in process parameters. Talc also can be used as reinforced material since it is cheap and will provide ease in processing.

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Conflict of Interest. The authors declare no conflict of interest.

References

Arif, M.F., Saintier, N., Meraghni, F., Fitoussi, J., Chemisky, Y. 2014. Multiscale fatigue damage characterisation in short glass fiber reinforced polyamide-66. *Composites Part B: Engineering*, **61:** 55-65.

Basso, M., Piselli, A., Simonato, M., Furlanetto, R., Pupure, L. 2019. Effect of food chemicals and temperature on mechanical reliability of bio-based glass fibers reinforced polyamide. *Composites Part B: Engineering*, **157:** 140-149.

Bernasconi, A., Conrado, E., Hine, P. 2015. An experimental investigation of the combined influence of notch size and fibre orientation on the fatigue strength of a short glass fibre reinforced polyamide 6. *Polymer Testing*, **47:** 12-21.

Chaichanawong, J., Thongchuea, C., Areerat, S. 2016. Effect of moisture on the mechanical properties of glass fiber reinforced polyamide composites. *Advanced Powder Technology*, **27:** 898-902.

Essabir, H., Rodrigue, D., Bouhfid, R., Qaiss, A.E.K. 2018. Effect of nylon 6 (PA6) addition on the properties of glass fiber reinforced acrylonitrile-butadiene-styrene. *Polymer Composites*, **39:** 14-21.

Feldmann, M., Bledzki, A.K. 2014. Bio-based polyamides reinforced with cellulosic fibres – processing and properties. *Composites Science and Technology*, **100:** 113-120.

Fernandes, F.C., Gadioli, R., Yassitepe, E., Paoli, M.A.D. 2017. Polyamide-6 composites reinforced with cellulose fibers and fabricated by extrusion: Effect of fiber bleaching on mechanical properties and stability. *Polymer Composites*, **38:** 299-308.

Frihi, D., Layachi, A., Gherib, S., Stoclet, G., Masenelli-Varlot, K. 2016. Crystallization of glass-fiber-reinforced polyamide 66 composites: Influence of glass-fibre content and cooling rate. *Composites Science and Technology*, **130:** 70-77.

Garcia, C., Trendafilova, I., Zucchelli, A. 2018. The effect of polycaprolactone nanofibers on the dynamic and impact behavior of glass fibre reinforced polymer composites. *Journal of Composites Science*, **2:** 43.

Graupner, N., Albrecht, K., Ziegmann, G., Enzler, H., Müssig, J. 2016. Influence of reprocessing on fibre length distribution, tensile strength and impact strength of injection moulded cellulose fibre-reinforced polylactide (PLA) composites. *Express Polymer Letters*, **10:** 647-663.

Mortazavian, S., Fatemi, A. 2015. Effects of fibre orientation and anisotropy on tensile strength and elastic modulus of short fiber reinforced polymer composites. *Composites Part B: Engineering*, **72:** 116-129.

Nagakura, M., Tanimoto, Y., Nishiyame, N. 2017. Effect of fiber content on flexural properties of glass fiber-reinforced polyamide-6 prepared by injection molding. *Dental Materials Journal*, **36:** 415-421.

Ning, F., Cong, W., Qiu, J., Wei, J., Wang, S. 2015. Additive manufacturing of carbon fiber reinforced thermoplastic composites using fused deposition modeling. *Composites Part B: Engineering*, **80:** 369-378.

Palazzetti, R. 2015. Flexural behaviour of carbon and glass fiber composite laminates reinforced with nylon 6,6 electrospun nanofibers. *Journal of Composite Materials*, 1-7.http://doi.org110.1177/0021998314565410.

Pickering, K.L., Efendy, M.G.A., Le, T.M. 2016. A review of recent developments in natural fibre composites and their mechanical performance. *Composites Part A: Applied Science and Manufacturing*, **83:** 98-112.

Saba, N., Tahir, P.M., Jawaid, M. 2014. A review on potentiality of nano filler/natural fiber filled polymer hybrid composites. *Polymers*, **6:** 2247-2273.

Sethi, S., Ray, B.C. 2015. Environmental effects on fibre reinforced polymeric composites: evolving reasons and remarks on interfacial strength and stability. *Advance of Colloid Interface Science*, **217:** 43-67.

Teixeira, D., Giovanela, M., Gonella, L.B., Crespo, J.S. 2015. Influence of injection molding on the flexural strength and surface quality of long glass fibre-reinforced polyamide 6.6 composites. *Materials and Design,* **85:** 695-706.

Withers, G.J., Yu, Y., Khabashesku, V.N., Cercone, L., Hadjiev, V.G. 2015. Improved mechanical properties of an epoxy glass–fibre composite reinforced with surface organomodified nanoclays. *Composites Part B: Engineering*, **72:** 175-182.