MATTER: International Journal of Science and Technology
ISSN 2454-5880

Gonenli and Yeni, 2018

Volume 4 Issue 1, pp.162-179

Date of Publication: 1st June 2018

DOI-https://dx.doi.org/10.20319/mijst.2018.41.162179

This Paper Can Be Cited As: Gönenli, C., & Yeni, E. (2018). Effect of Various Pulling Speeds on the Mechanical Properties of Various Fiber Mixture Combinations of Polyamide 6 And 6.6 Materials. MATTER: International Journal of Science and Technology, 4(1), 162-179.

EFFECT OF VARIOUS PULLING SPEEDS ON THE MECHANICAL PROPERTIES OF VARIOUS FIBER MIXTURE COMBINATIONS OF POLYAMIDE 6 AND 6.6 MATERIALS

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Abstract

Nowadays, thermoplastic composites have increasingly wide application areas due to their high stiffness and impact strength properties, superior fracture toughness, long duration of raw material shelf life and ease of production processes. Besides, they provide safer work environment. In this study, it has been examined that how the pulling speeds effects mechanical properties of thermoplastic composites. Non-reinforced, 15 percent reinforced and 30 percent reinforced polyamide 6 and polyamide 6.6 samples are produced with using plastic injection molding method and they are subjected to tensile testing at five different pulling speeds using the Tensile Testing Device. The results obtained from testing and those gathered from the plastics manufacturer company are compared with data obtained from the literature to check mechanical properties of thermoplastic composites which have been used in pulling speed test. It is observed that the experimental results were highly consistent with those in literature. According to these *results, the positive effect of higher pulling speeds is observed. In this way, the different types of unreinforced and fiber glass reinforced polyamide 6 / polyamide 6.6 samples behavior under different pulling speeds have been determined. The results are in similar behavior with all types of polyamides. In order to gain an understanding of the effect of the overall testing procedure for all speeds, stress–strain graphics are constructed.*

Keywords

Polyamide 6, Polyamide 6.6, pulling speed, Fiber glass composite, Mechanical properties

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1. Introduction

Rapidly developing technology necessitates challenges on materials science, which is the basic requirement of industrial developments. However, materials found on earth cannot keep up with developing technology needs and cannot meet the requests solely. The Second World War has revealed technological warfare and aviation. As a result of this, composite materials have taken a part in global literature. For example, in a study that was published in 2017, a new technology was explained that glass powder/pet composite has been used for the construction of living tower (Dioktyanto et al, 2017). The aim here is to find a unique material which is a combination of different materials in desired properties. In short, composite material consists of two or more materials selected according to their desired properties brought together to create a new material as a macro structure in certain physical proportions.

Fiber reinforced thermoplastic compounds may be processed by conventional methods, such as injection moulding, and offer improvements in mechanical properties over unreinforced ones. These composites compete with metals in many engineering applications because of their ease of fabrication, light weight and economy. However, there are problems concerning material defects such as voids or cracks that may be present or initiated in one of the three regions: the matrix, the fiber or the fiber/matrix interface. The mechanical properties of thermoplastic composites containing short fibers have been the subject of much attention. These properties result from a combination of the fiber and the matrix properties and the ability to transfer stresses across the fiber/matrix interface, but also depend on the injection conditions such as screw and barrel parameters, mould temperature and design (Bouchaib et al., 2006).

It is known that the first glass fiber is produced in the 16th century BC and in 1877 some findings about use of fiber glass in industry have been discovered. Nowadays fiberglass is widely used in the market. Fiber reinforced plastics are used as liquid tanks, roof panels, wherries, etc. Also, in a study published in 2017, the effect of polyamide composites on heavy metal ions in the water has been investigated. It has been explained how polyamide composites are used to prevent water pollution directly affecting human health (Thu Hong & Dung Thi, 2017). In another study published in 2017, it has been investigated that how the humid environment effects the mechanical properties of polyamide materials (Le Gac, Arhant, Le Gall & Davies, 2017).

2. Fiberglass Reinforced Polyamide

2.1 Polymer

In practice, the composite consists of two phases. The first one is matrix - called the main phase - and the other one is fiber - called the secondary phase-. According to the type of matrix, composites are divided into five different classes (Güleşen, 2005).

- Metal matrix composites: These composites are commonly used in automotive, aerospace and defense industries.
- Ceramic matrix composites: These composites are used in production of rocket warhead, space vehicles, armor, military purposes, and in addition to these areas it is used as a biomaterial in the human body.
- Polymer matrix composites: These composites are used intensely in different areas because of their corrosion resistance in marine applications, being lightweight in automotive and other transportation industries, sporting goods and interior decoration.
- Carbon matrix composites: These composites are used in rocket head, shields of spacecraft, clutch and brake pad.
- Nano-composites: These are used to improve mechanical, flammability and thermal properties of composites.

Monomer is the name given to small chemical molar mass. Monomers are connected by covalent bonds to each other and they compose larger molecules. Medium sized molecules are called oligomer and monomers form from the combination of hundreds of much larger macro-molecules called polymers. Polymers are separated into three groups as elastomers, thermosets and thermoplastics (Yılmaz, 2010).

Thermoplastic polymers has less usage areas than termoset ones because of difficulty in production and expensive raw material. They provide lower processing quality at room temperature. However there are some advantages such as high rigidity and impact strength characteristics, superior fracture toughness, the length of the shelf life of raw materials, hardening process due to the need for organic solvents to provide a safe working environment. Figure 1 shows a representation of commercial thermoplastics.

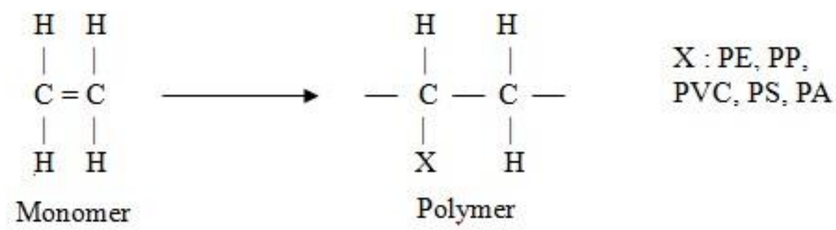

Figure 1: *Commercial thermoplastics (Strong, 2005).*

Polyamide 6 and polyamide 6.6 which are used in this study are thermoplastic materials generally known as nylon in the market. Polyamides are one of the most important groups of engineering plastics with their use in sports equipment industry, textile, and automotive.

Nylon has some important characteristics as high mechanical strength, abrasion resistance, low coefficient of friction and high upper temperature limit. Nylons are expensive but are preferred due to their significant characteristics.

2.2 Fiberglass

Composite are divided into five classes according to the form of components:

- Particle reinforced composites; macroscopic or microscopic particles that create the matrix materials.
- Fiber reinforced composites; have anisotropic structure, transmits the load to the fibers and the fibers carry the load.
- Sheet composites; phases of reinforcement elements consisting of sheet-shaped composites.
- Laminate composites; different component plates are combined like a sandwich.
- Filled composites; skeleton having a structure produced by form, fill reinforcing material composites.

When hard, durable, elastic modulus fibers are added into soft and ductile matrix, high tensile strength, modulus of elasticity, fatigue strength and fracture resistance characteristics are improved. While matrix material provides toughness by transferring forces to the fibers, fibers carry most of the applied load. Although fibers may be knitted, wick or strip, they are used directional fibers into layers. There are six different fiber type used commonly. These are named as Boron, aramid, Alumina, Silicon Carbide, Glass and Carbon. Fiber glass, used in our study, come into prominence with the features such as high tensile strength, low thermal resistance, insulation, low price and ease of production (Karadeniz, 2006).

2.3 Literature Review

It can be seen that there is a proportion between the amount of fiberglas addition and the mechanical properties of the composite when polyamide 6, polyamide 6.6 and their fiberglass reinforced mixtures are examined. Figure 2 shows stress-strain curves for different fiberglass amounts and Figure 3 shows the effect of fiber volume.

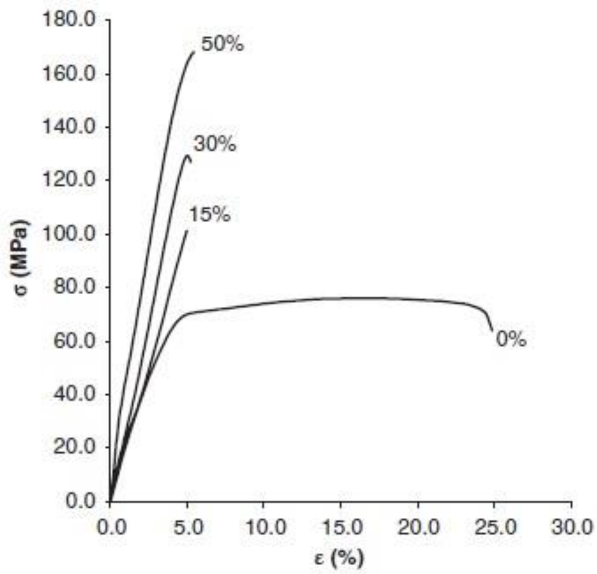

Figure 2: *Stress-strain curves for different reinforcements (Bouchaib, Abdellatif, Noureddine, Salim and Abdellatif, M., 2006).*

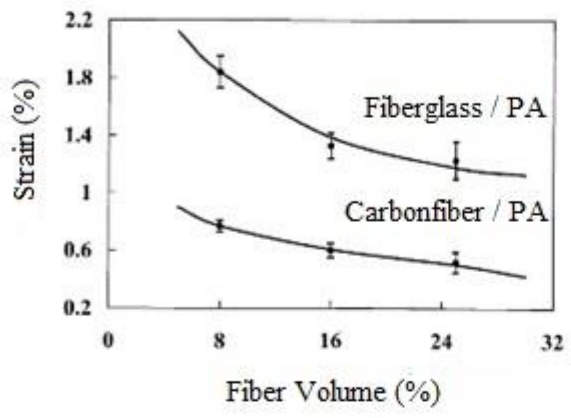

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Figure 3: *Effect of fiber volume (Fu, Lauke, Mader, Yue and Hu, 2000).*

3. Experimental Study

3.1 Production

All of the samples were injected into to the mold with thermoplastic injection method in accordance with ISO 527-1. In this method, the material is fed into the injection machine in granule form. The material becomes fluid in a homogeneous mixture in the heating zone. The molten material is transmitted from the heating zone to the output end. It is injected to the closed mold where it is cooled in room temperature. The complex patterns can be manufactured with this method easily. A schema about thermoplastic injection method is given in Figure 4, thermoplastic injection mold is given in Figure 5 and the sample used in tests is given in Figure 6.

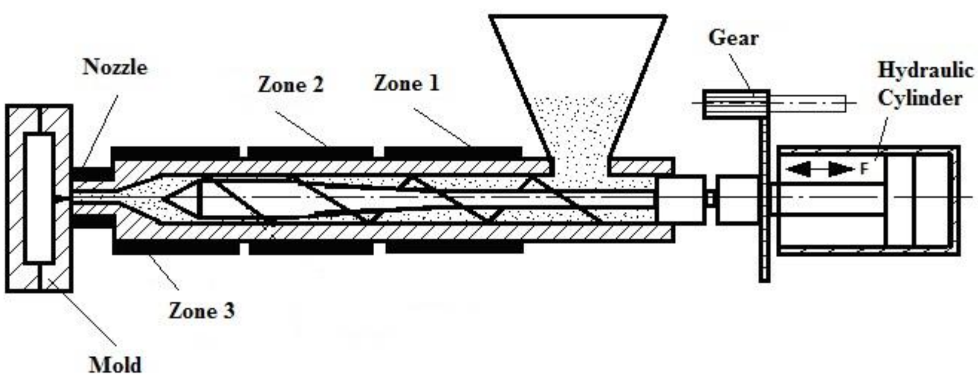

Figure 4: *Thermoplastic injection method.*

Figure 5: *Thermoplastic injection mold.*

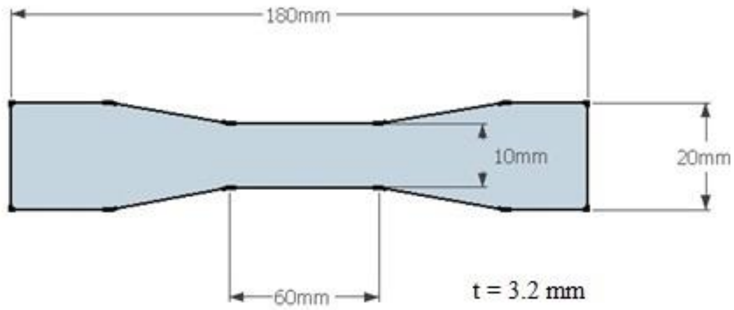

Figure 6: *Experimental study sample.*

3.2 Universal Tensile Testing Machine and Tensile Test Specimens

All of the samples were produced by thermoplastic injection molding, and their test results were obtained on the tensile machine. In determining the pulling speeds, ISO 527 standards were considered. The pulling speeds were decided as 5, 10, 20, 50 and 100 mm/min, since increasing of pulling speed was desired in a linear logarithmic line. The pulling speed graphic is given in Figure 7.

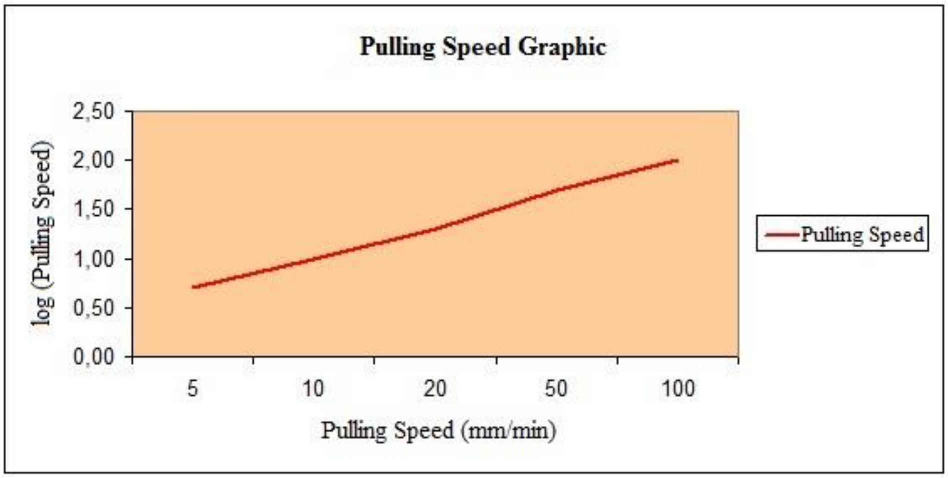

Figure 7: *Pulling speed graphic.*

For each condition, the tests were repeated three times for the reliability of experimental study. The data read by the video extensometer fixed on the tensile machine was transferred moment by moment to the computer during the experiment. Tensile testing machine is shown in Figure 8.

Figure 8: *Tensile machine for tensile test.*

Types of materials used in tensile testing can be examined into two groups. The first group material has clearly detectable yield strength and the second one does not have. 0.2% plastic deformation point in the stress-strain curve is called the yield strength or proof strength for the nonapparent material group. The yield strength point may be 0.1% or 0.5% instead of 0.2% in some special cases but this must be informed on the study. Nonapparent material's stress-strain curve is given in Figure 9.

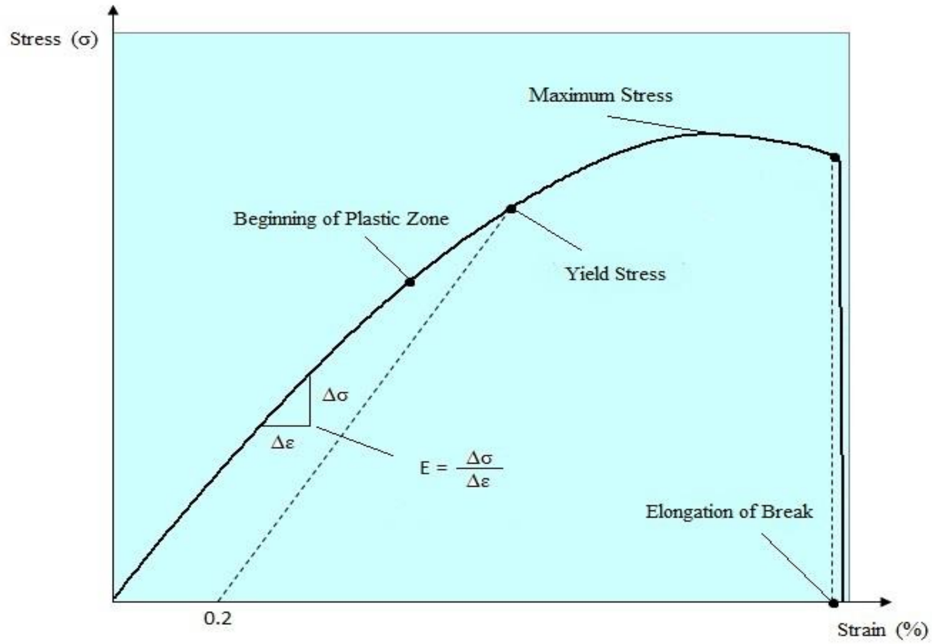

Figure 9: *Stress-strain curve for nonapparent material.*

The plastic material used in the experiment has nonparent yield strength. Thus, a parallel line is drawn to 0.2% plastic deformation based on the initial linear behavior of the stress-strain curve. The intersection of the line and the curve gives us the yield strength. Material is in the elastic deformation zone from beginning to this point. After that, stress causes permanent deformation since it enters the plastic deformation zone.

We have six different samples for tensile test. Three of them belong to polyamide 6 and the other three belong to polyamide 6.6. Their reference values which were taken from manufacturers are given in Table 1.

Table 1: *Reference values of samples.*

MATERIAL NAME	MANUFACTURER	MAXIMUM STRESS (MPa)	ELONGATION AT BREAK	ELASTICIY MODULUS (MPa)
PA6	TECOMID	70	…	3500
15% REINFORCED PA6	EPLAMID	70 - 110	%5 - %11	3800 - 4900
30% REINFORCED PA6	AKULON	80	%3.6	6900
PA6.6	ULTRAMID	50 - 85	%5 - %20	1100 - 3100
15% REINFORCED PA6.6	VYDYNE	83 - 130	%3 - %11	4300 – 6700
30% REINFORCED PA6.6	UPAMID	> 130	> %3	> 6500

3.3 Polyamide 6 Results

Each material has five different pulling speeds and five different stress-strain curves. The curves were compared to understand the effect of the pulling speed on tensile properties at room temperature. They also show that the non-reinforced polyamide and fiberglass reinforced polyamide's mechanical properties. Figures 10, 11 and 12 show how varying the pulling speeds affect the polyamide 6 samples.

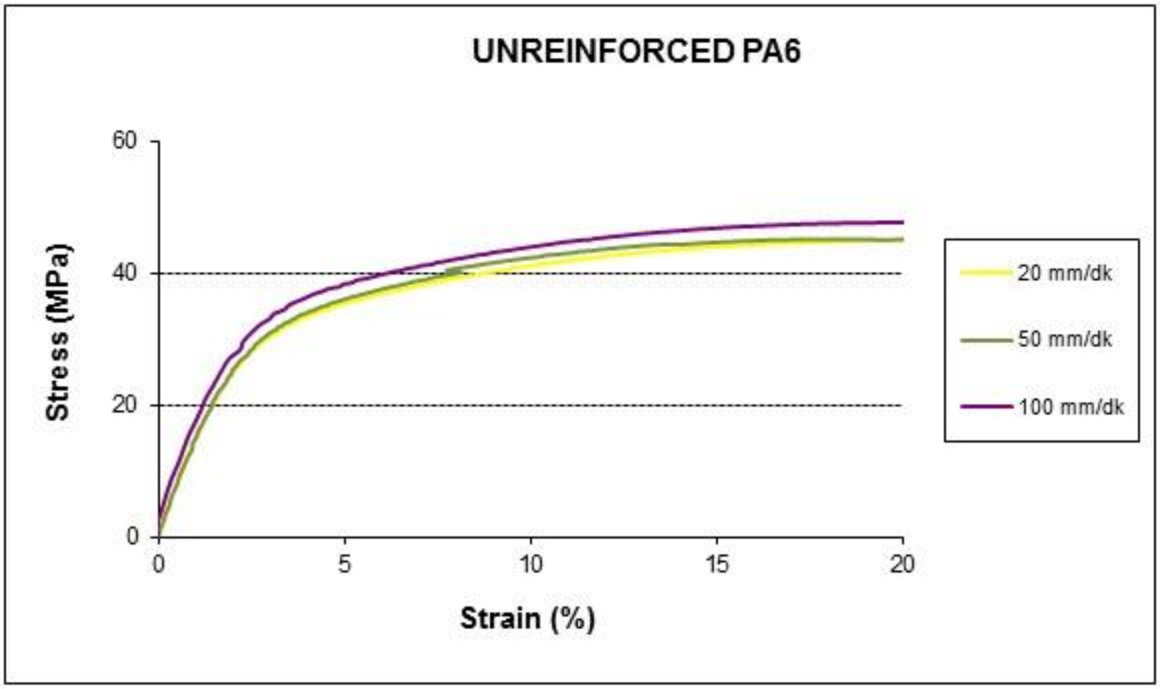

Figure 10: *Effect of pulling speed in unreinforced polyamide 6.*

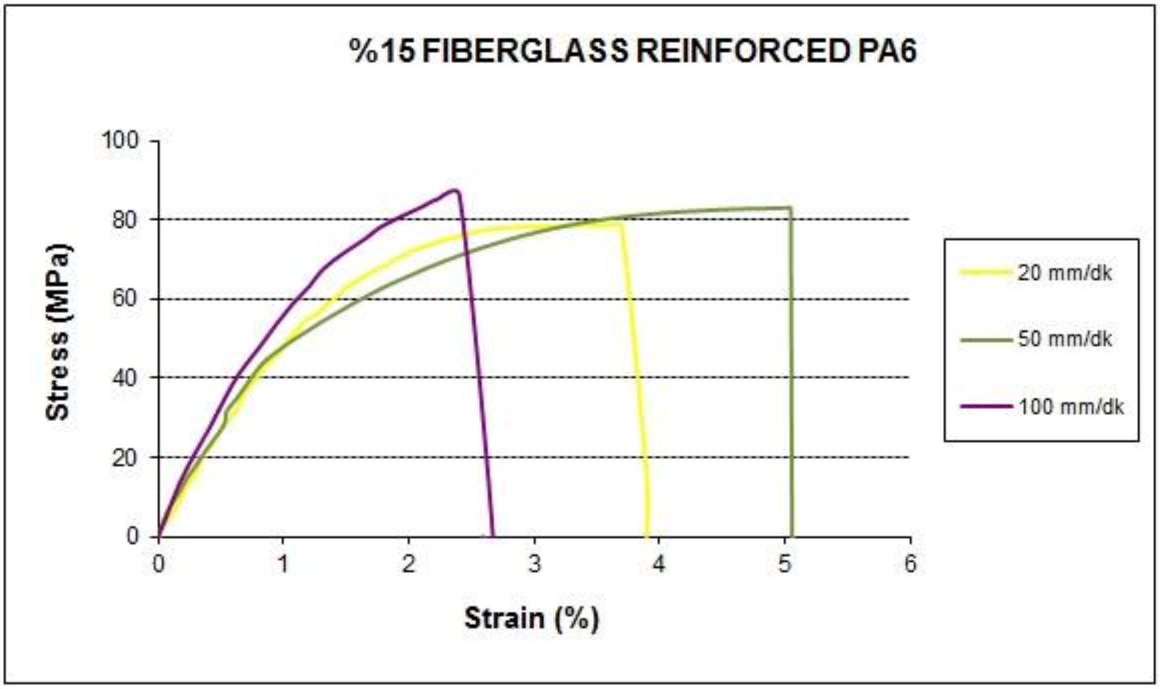

Figure 11: *Effect of pulling speed in %15 fiberglass reinforced polyamide 6.*

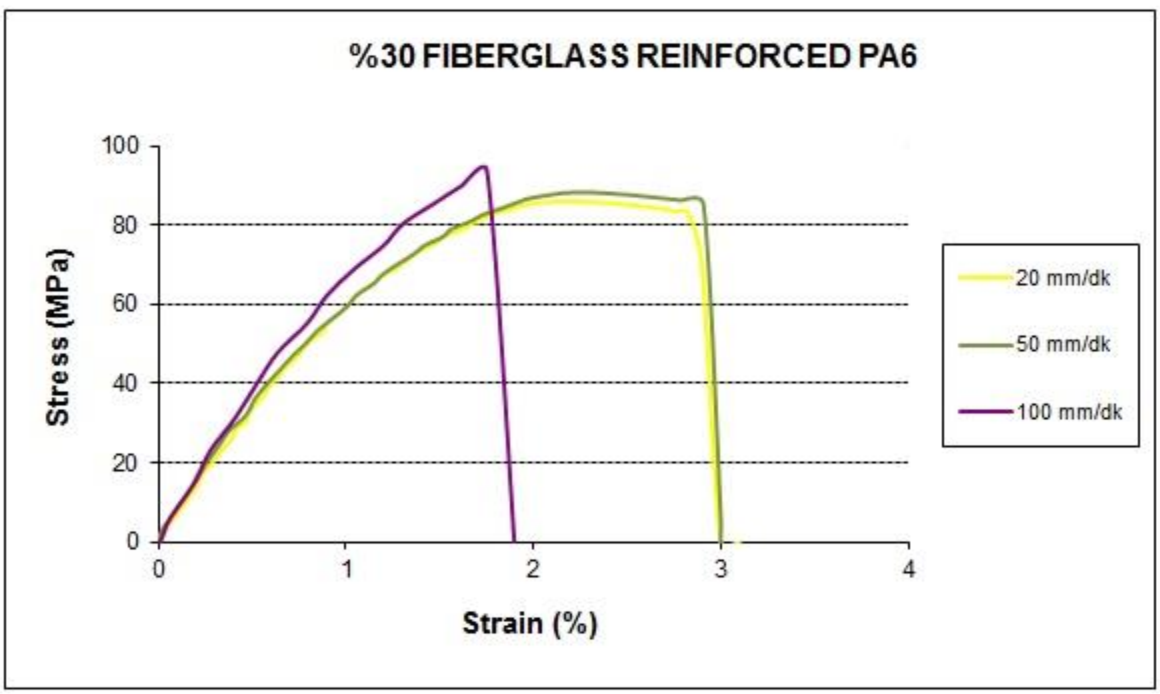

Figure 12: *Effect of pulling speed in %30 fiberglass reinforced polyamide 6.*

The effect of pulling speed can be seen in the figures. The effect of pulling speed shows itself at higher pulling speeds, so 5 mm/dk and 10 mm/dk are eliminated from the figures. It can be said that the mechanical properties are directly affected with increasing pulling speeds. It can be seen in elasticity modulus table of polyamide 6 (Table 2), elongation at break table of polyamide 6 (Table 3), maximum stress table of polyamide 6 (Table 4) and yield strength table (Table 8).

Table 2: *Elasticity modulus for all polyamide 6 samples.*

ELASTICITY MODULUS (MPa)	5 mm/min	10 mm/min	20 mm/min	50 mm/min	100 mm/min	References
UNREINFORCED PA6	**1439**	**1698**	**1736**	**1822**	**2041**	3500
15% FIBERGLASS REINFORCED PA6	**5333**	**5553**	**5801**	**6612**	**7205**	3800-4900
30% FIBERGLASS REINFORCED PA6	**6896**	**6954**	**6920**	**7552**	**8067**	6900

Table 3: *Elongation at break for all polyamide 6 samples.*

ELONGATION AT BREAK	5 mm/min	10 mm/min	20 mm/min	50 mm/min	100 mm/min	References
UNREINFORCED PA6	**> %100**	**> %100**	**> %100**	**> %100**	**> %100**	…
15% FIBERGLASS REINFORCED PA6	**%4.3**	**%4.67**	**%3.90**	**%5.06**	**%2.67**	%5 - %11
30% FIBERGLASS REINFORCED PA6	**%2.79**	**%3.13**	**%3.00**	**%3.00**	**%1.90**	%3.6

Table 4: *Maximum stress for all polyamide 6 samples.*

MAXIMUM STRESS (MPa)	5 mm/min	10 mm/min	20 mm/min	50 mm/min	100 mm/min	References
UNREINFORCED PA6	**44.32**	**43.82**	**45.01**	**45.08**	**47.64**	70
15% FIBERGLASS REINFORCED PA6	**75.16**	**77.44**	**78.66**	**83.00**	**86.39**	70 - 110
30% FIBERGLASS REINFORCED PA6	**78.96**	**80.58**	**86.35**	**92.94**	**93.72**	80

3.4 Polyamide 6.6 Results

If we examine the effect of pulling speeds for three different mixture of polyamide 6.6, it can be seen that the pulling speed effect on mechanical behaviors of polyamide 6.6 is similar to polyamide 6. Five different speeds of unreinforced, 15% fiberglass reinforced and 30% fiberglass reinforced polyamide 6.6 samples are given in Figures 13, 14 and 15.

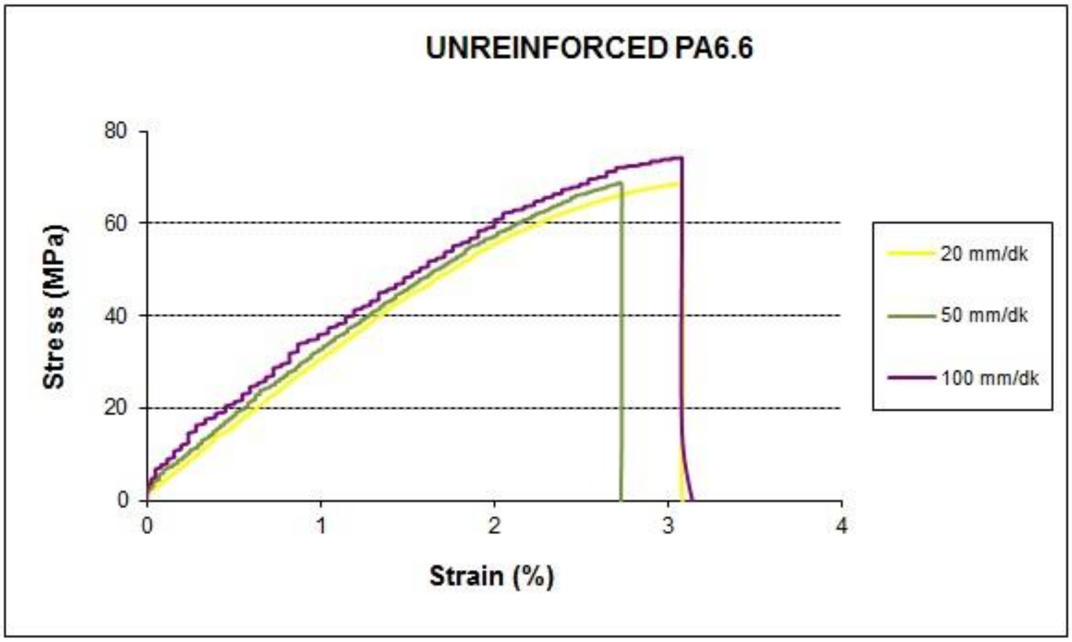

Figure 13: *Effect of pulling speed in unreinforced polyamide 6.6.*

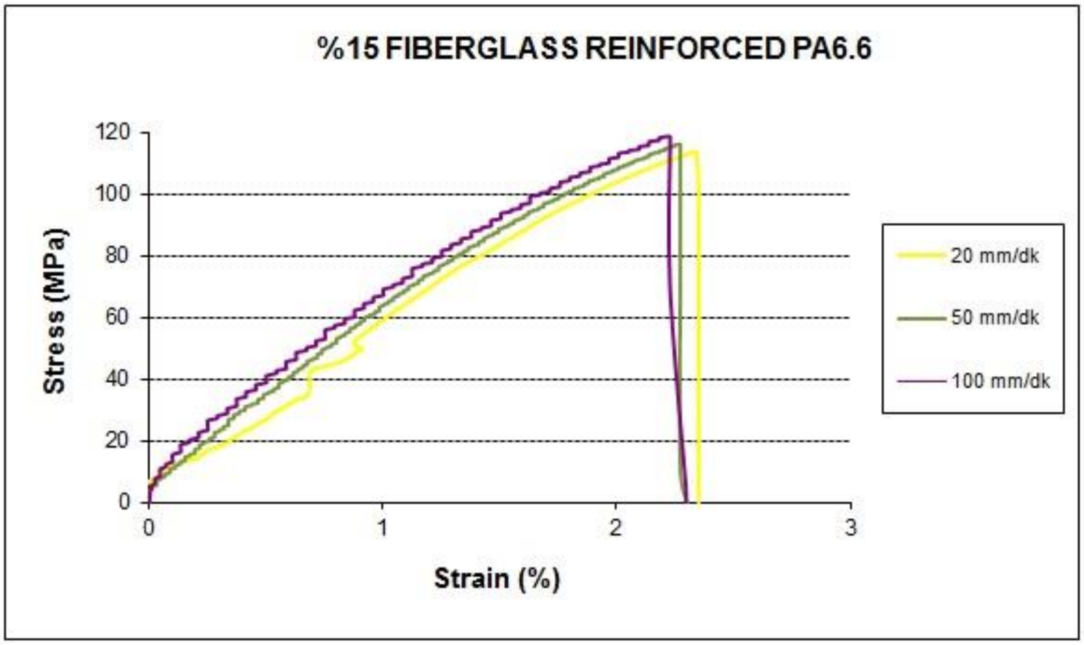

Figure 14: *Effect of pulling speed in %15 fiberglass reinforced polyamide 6.6.*

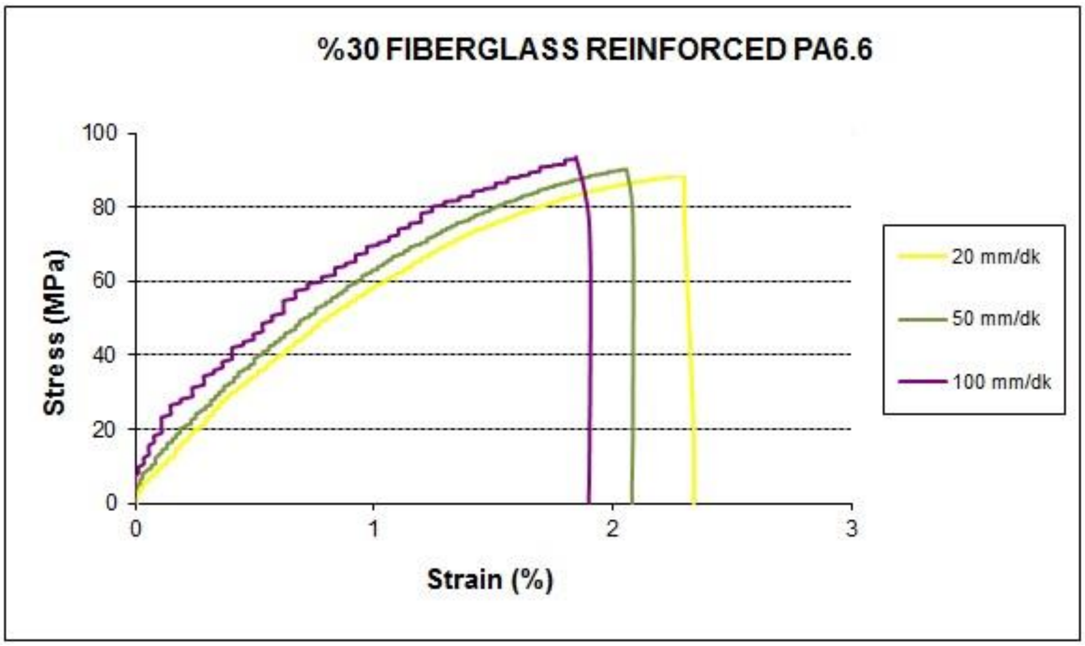

Figure 15: *Effect of pulling speed in %30 fiberglass reinforced polyamide 6.6.*

The effect of pulling speed can be seen in the figures. The effect of pulling speed shows itself at higher pulling speeds, so 5 mm/dk and 10 mm/dk are eliminated from the figures, again. As it was mentioned before, the mechanical behaviors are similar to polyamide 6 mixtures. It can be seen in elasticity modulus table of polyamide 6.6 (Table 5), elongation at break table of polyamide 6.6 (Table 6), maximum stress table of polyamide 6.6 (Table 7) and yield strength table (Table 8).

Table 5: *Elasticity modulus for all polyamide 6.6 samples.*

ELASTICITY MODULUS (MPa)	5 mm/min	10 mm/min	20 mm/min	50 mm/min	100 mm/min	References
UNREINFORCED PA6.6	**3460**	**3703**	**3837**	**4297**	**4941**	3100
15% FIBERGLASS REINFORCED PA6.6	**5992**	**6435**	**7251**	**7439**	**9008**	4300-6700
30% FIBERGLASS REINFORCED PA6.6	**6988**	**7379**	**7616**	**8819**	**10252**	> 6500

Table 6: *Elongation at break for all polyamide 6.6 samples.*

ELONGATION AT BREAK	5 mm/min	10 mm/min	20 mm/min	50 mm/min	100 mm/min	References
UNREINFORCED PA6.6	**%3.67**	**%3.04**	**%3.09**	**%2.74**	**%3.15**	%5 - %20
15% FIBERGLASS REINFORCED PA6.6	**%2.32**	**%2.41**	**%2.35**	**%2.32**	**%2.30**	%3 - %11
30% FIBERGLASS REINFORCED PA6.6	**%2.29**	**%2.44**	**%2.34**	**%2.09**	**%1.90**	> %3

Table 7: *Maximum stress for all polyamide 6.6 samples.*

MAXIMUM STRESS (MPa)	5 mm/min	10 mm/min	20 mm/min	50 mm/min	100 mm/min	References
UNREINFORCED PA6.6	**63.70**	**66.36**	**69.38**	**68.51**	**74.15**	50 - 85
15% FIBERGLASS REINFORCED PA6.6	**109.46**	**113.80**	**116.40**	**116.60**	**108.53**	83 - 130
30% FIBERGLASS REINFORCED PA6.6	**80.78**	**82.87**	**88.34**	**90.03**	**93.52**	> 130

3.5 Yield Strength

For the curve shown in the Figure 9, the yield strength was approximately evaluated based on 0.2% elongation. Accordingly, the yield strength values of polyamide 6, polyamide 6.6 and their fiberglass reinforced mixtures are shown in Table 8.

Table 8: *Yield strength values for all polyamide 6 and polyamide 6.6 samples.*

YIELD STRENGTH (MPa)	5 mm/min	10 mm/min	20 mm/min	50 mm/min	100 mm/min
UNREINFORCED PA6	**17.48**	**22.24**	**24.15**	**26.51**	**30.47**
15% FIBERGLASS REINFORCED PA6	**45.60**	**48.71**	**56.77**	**62.69**	**71.52**
30% FIBERGLASS REINFORCED PA6	**60.26**	**65.72**	**67.33**	**72.61**	**85.43**
UNREINFORCED PA6.6	**50.42**	**55.93**	**57.38**	**63.96**	**70.35**
15% FIBERGLASS REINFORCED PA6.6	**83.03**	**92.31**	**97.14**	**103.67**	**109.56**
30% FIBERGLASS REINFORCED PA6.6	**66.65**	**71.98**	**73.32**	**80.01**	**87.10**

4. Conclusion

As a result of the experimental study, the effects of the pulling speed with various fiberglass reinforcement polyamides have been carried out. The tensile properties of various samples are obtained. According to this data, the experimental study has succeeded for all of the polyamide 6 and polyamide 6.6 materials.

Consequently, increasing the pulling speed revealed clearly the positive effects of fiberglass reinforcement and this has become clearer in higher pulling speed levels. The yield strength, modulus of elasticity and maximum stress has higher values with increasing the pulling speed. Also the elongation at break has lower values. This also shows that increasing the volume of fiberglass reinforcement provides a brittle form to the composite. Similarly, increasing the pulling speed revealed clearly the positive effects of fiberglass reinforcement and this has become clearer in higher pulling speed levels. In comparison polyamide 6 and polyamide 6.6, both literature and experiments show that polyamide 6 is more ductile than polyamide 6.6 so polyamide 6 has to be worked in low stress.

For the scope of future research, these data's can be used for designing the engineering structures in different usage areas. Especially under dynamic loads, it has been known now with this work that thermoplastic composites have much more strength when the load is applied suddenly.

Acknowledgment

This paper is reproduced from Dokuz Eylul University Graduate School of Natural and Applied Sciences Master of Science thesis. I would like to thank my supervisor Prof. Dr. Emine Çınar YENİ for her unique help at all stages of this study.

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