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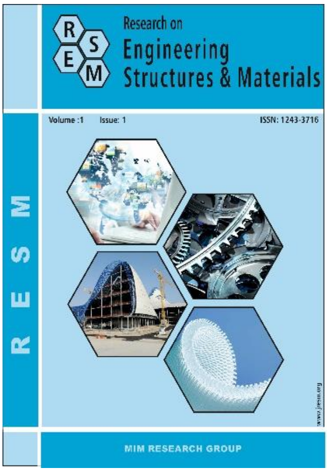

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Online Publication Date: 25 Mar 2016
URL: http://www.jresm.org/archive/resm2016.39ma0216.html
DOI: http://dx.doi.org/10.17515/resm2016.39ma0216

Journal Abbreviation: *Res. Eng. Struct. Mat.*

To cite this article
Ipek H, Cuvalcı H. Wear behaviour of the glass fiber reinforced cast polyamide in pin-on-disc type wear machine. *Res. Eng. Struct. Mat.*, 2017; 3(1): 77-87.

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Research Article

Wear behaviour of the glass fiber reinforced cast polyamide in pin-on-disc type wear machine

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Article Info

Article history:
Received 16 Feb 2016
Revised 9 Mar 2016
Accepted 23 Mar 2016

Keywords:
Castamide, E-glass fiber, Polymer Matrix Composites (PMCs), Wear, Pin-On-Disc

Abstract

In this study, randomly oriented discontinuous chopped glass fiber (E-glass) reinforced cast polyamide (PA6G or castamide) composites were produced by pressure molding method. Two different sample groups were produced with different method. First group was produced under constant pressure at different molding temperature, second one was produced under constant temperature with different pressure. Produced samples friction tests were performed by using a pin-on-disc type friction test machine under dry sliding condition. The performance of the friction tests was carried out different distances and loads. Wear loss of the samples were detected and worn surfaces were investigated with scanning electron microscope (SEM) for determination of the wear mechanism.

It was concluded that maximum wear loss was observed at the 300 °C molding temperature in the first group. On the other hand, total wear in second group was decreased with increasing molding pressure according to first group.

1. Introduction

Polymer based materials have been used over the last few decades because of the demands for light weight, corrosion resistance, cost saving and good wear behavior have forced the replacement of metallic components with polymer composites [1-3]. Most of the applications need to good wear resistance with mechanical strength together. Unfortunately, combination of these properties usually unavailable [4]. The tribological effect between the pin and disc reveals of how the reinforcement plays a staminal act in improving the friction coefficient [5]. In addition, polymers tribological applications has been limited service temperature when friction-induced heat is increased its glass transition temperature at the sliding surface [6]. This conditions have caused to the improvement of copolymers and reinforced polymers [4]. Most of the reinforcement materials selected as fiber due to high mechanical performance and good wear performance [7-9]. This reinforced polymer based composites known as polymer matrix composites (PMCs) [1, 2, 10]. The numerous fibers used for PMCs as glass fibers, aramid fibers and carbon fibers, etc. But glass fibers are used most widely because they are easy to fabricate and are inexpensive compared to other fibers type. In general, glass fiber-reinforced PMCs show good tribological properties [1]. Reinforcement materials can be permanent or impermanent. In this study, chopped (impermanent) and randomly oriented glass fibers (E-GF) were used as reinforcement and cast polyamide (PA6G or castamide) used as matrix material. Chopped glass fiber reinforced PMCs are increasing the use of new aged materials which is important in friction and wear applications [1, 10]. Friction and wear are the most common problem in industry [11, 12]. There are two main wear

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DOI: http://dx.doi.org/10.17515/resm2016.39ma0216

mechanisms as abrasive and adhesive. These wear mechanisms can be useful for understand of the composite properties. Characteristically, adhesive wear shows that material transfer from soft polymeric material to the hard counter face [13]. Other one is the major industrial problem which is erosive wear of engineering components by abrasive wear [14]. There is no pin-on-disc friction and wear performance research about chopped glass fiber reinforced cast polyamide in given composition rate in the literature. Therefore, this study focused on wear performance of these composites at different manufacturing parameters.

2. Materials and Methodology

Chopped E-glass fiber reinforced castamide composites was produced with injection molding method. Castamide was provided in the form of rod about 100mm from Polikim firm in Turkey [15]. Rod castamide material were cut with hydraulic saw for produce sawdust and chips about varying sizes from 100 μm to 3cm. Macroscopic images of the castamide and glass fibers can be seen in Fig. 1.

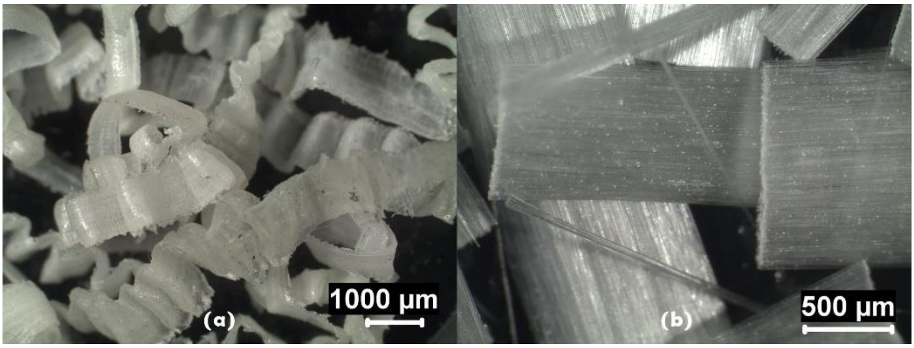

Fig. 1 Macroscopic images of the castamide and glass fibers

Sawdust and chips were used for matrix material. Reinforcement material was provided from Glass Fiber Company in Turkey [16]. Some of the properties of castamide and E-glass fiber were given in Table 1.

Table 1 Properties of the castamide and E-glass fiber

Castamide (PA6G)			E-Glass (E-GF)		
Properties	Unit	Value	Properties	Unit	Value
Density	*g/cm³*	1.15	Density	*g/cm³*	2.56
Water absorption	*%*	7	UTS	*MPa*	3445
UTS	*MPa*	80	Fibre Length	*mm*	3
Modulus of elasticity	*GPa*	4	Fibre Radii	*μm*	13
Impact strength (Izod, notched)	*kJ/m²*	5.6	Modulus of elasticity	*GPa*	76
			Chemical composition	*% (wt)*	52.4 SiO_2 14.4 Al_2O_3 10.6 B_2O_3 4.6 MgO 17.2 CaO 0.8 other
Hardness (Shore D)	*Shore D*	84			
Melting Temperature	*°C*	220			

Compound of the composites was selected as 50% wt. castamide and 50% wt. E-glass fiber. Volumetric ratio was calculated with Eq. (1) and volumetric ratio was found as 31% castamide and 69% E-glass fiber. This compound ratio was provided the best mechanical properties except impact strength and elongation value from previous study [17]. In this study, the effect of the temperature was investigated on the mechanical properties first.

Best mechanical strength was found at 300 °C molding temperature in this section. And then molding pressure effect was investigated in various molding pressure (9, 14, 20, 25 MPAs) before the wear behavior of the composites at a constant compound ratio. There was no sizing or intermediary agent(s) utilized in this study.

Theoretical density was calculated as 1.587 g/cm^3 from Eq. (2). Table 2 shows composite manufacturing parameters and actual density.

$$V_f = \frac{\frac{W_f}{\rho_f}}{\frac{W_f}{\rho_f}+\frac{W_m}{\rho_m}} x100 \quad (1)$$

Where, V_f: fiber volume (%), W_f: fiber weight (g), W_m: matrix weight (g), ρ_f: fiber density (g/cm^3), ρ_m: matrix density (g/cm^3).

$$\rho_c = \left(V_f x \rho_f\right) + \left(V_m x \rho_m\right) \quad (2)$$

Here, ρ_c: composite density (*g/cm^3*), V_f: volumetric fiber ratio (%), V_m: volumetric matrix ratio.

Table 2 Manufacturing parameters of composites and actual density

Group	Sample Codes	Moulding Temperature (°C)	Moulding Pressure (MPa)	Actual Density of the composites (g/cm^3)
Constant Pressure (First Group)	1	260	3.5	1.55
	2	280	3.5	1.42
	3	300	3.5	1.55
	4	320	3.5	1.55
Constant Temperature (Second Group)	5	300	9	1.50
	6	300	14	1.49
	7	300	20	1.46
	8	300	25	1.50

There is a difference between theoretical and actual density and it is called porosity. When Eq. (3) applied to the composites, porosity can be calculated. And the porosity was observed to vary between 2.3 % and 10.5%.

$$\%porosity = \frac{\Delta\rho}{\rho_0} x100 \quad (3)$$

Where, $\Delta\rho$: difference between theoretical and actual density, ρ_0: theoretical density.

2.1. Pin-On-Disc Test

The samples were cut in the form of pin about 7.5mmx8.5mmx50mm dimensions for pin-on-disc test machine's sample holder. Various sliding speeds and nominal contact pressure were used in literature from 0.01m/s to 4m/s and from 0.64MPa to 2.5 MPa, respectively. According to the literature friction and wear parameters were selected as constant sliding speed (0.367 m/s or 100rpm±2), track (70mm) and various nominal contact pressure (0.15, 0.3, 0.8, 1.5 MPa) at different times. Table 3 shows wear test parameters.

A computer controlled test machine was provided from Ducom Company. Schematic drawing of the pin-on-disc test machine can be seen in Fig. 2. Abrasive disc was selected as H11 hot work tool steel. A running in procedure was applied to the wear samples before wear test in varying times.

Table 3 Pin-on-disc test parameter

Time (h)	Load (kg)	Nominal Contact Pressure (MPa)	Track (mm)	Speed (rpm)	Sliding Speed (m/s)
5 10 15	1, 2, 5, 10	0.15, 0.3, 0.8, 1.5	70	100 (±2)	0.367

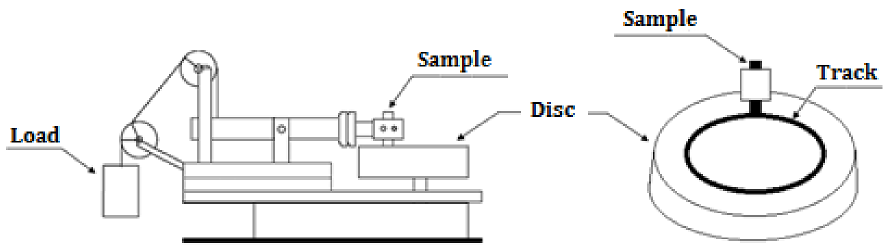

Fig. 2 Schematic drawing of the pin-on-disc test machine

Wear test was performed at room temperature and atmospheric humidity conditions without lubricant. Each wear test was applied only once caused of the humidity absorption capability of the castamide. After each test, weighting operation was performed with 0.1 mg precision balance (Ohaus-Pineer).

Surface roughness was measured with Marhsurf PS1 profilometer and wear mechanisms were investigated in a scanning electron microscope (SEM-Zeiss EVO LS10). Before SEM investigation, sample surface was sputtered with gold by using Emitech SC 7620 coating machine.

3. Results and Discussions

3.1. Wear Rate

After weight loss measured by balance the wear rate of samples was calculated with Eq. (4)

$$WearRate\left(\frac{mm^3}{m}\right) = \frac{Weight\ loss\ (g)}{Density\left(\frac{g}{mm^3}\right) x Distance(m)} \tag{4}$$

After 5 hrs (6600m) wear test samples show similar wear rate curve in general. Third sample's curve showed almost linear trend but the other curves showed suddenly increased after 5kg load. It can be seen from Fig. 3 that maximum wear rate was found at the fifth sample under 10 kg load. Wear rate was increased from 5kg to 10 kg at the rate of 87%.

Wear rate of the samples for 10 hrs test (13200m) can be seen in Fig. 4. One and four numbered samples show liner wear rate curve. Maximum wear rate was also determined at 10kg load just like 5 hour tests. Total wear rate was minimum on the sample two.

Fig. 5 shows 15 hrs (19800m) wear rate curves. Third sample shows unstable wear rate. Against long odds, 5kg load was bigger wear rate than 10kg wear rate. And the minimum wear rate was observed on the eighth sample.

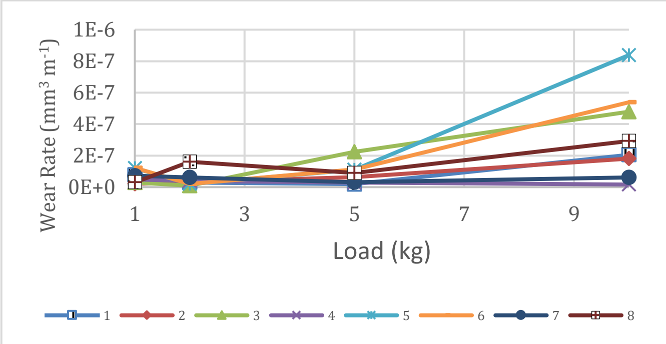

Fig. 3 Wear rate after 5 hrs testing

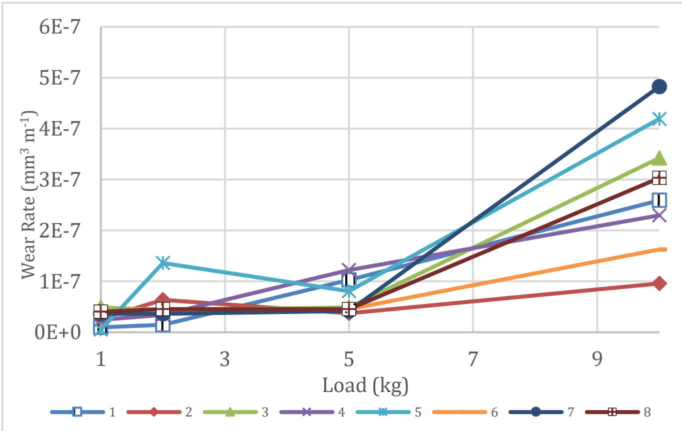

Fig. 4 Wear rate after 10 hrs wearing

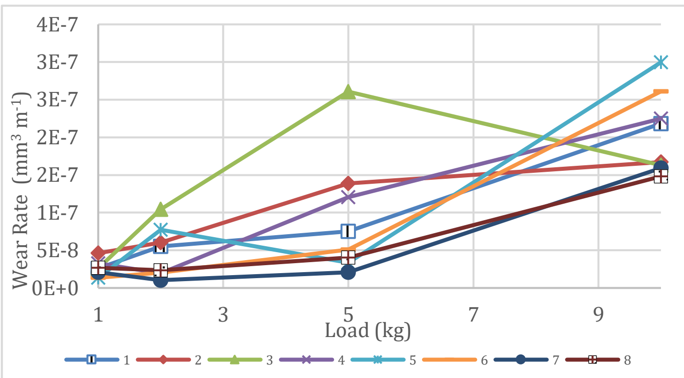

Fig. 5 Wear rate after 15 hrs wearing

3.2. Weight Loss

Composites wear resistance was detected by weight loss. And weighing of the specimens was obtained before and after each wear test experiment. Weight loss chart can be seen in Fig. 6. Chart shows the total wear loss after 120 hrs (5h, 10h, and 15h) wear process.

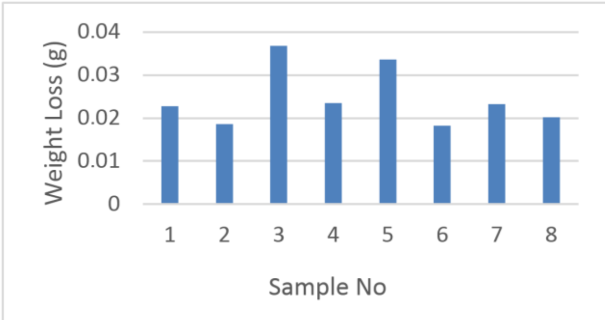

Fig. 6 Total weight loss

Two and six numbered samples show minimum wear loss about 0.02% (~ 0.018 g) but sample three shows maximum wear loss about 0.04% (~ 0.036 g). Effect of the randomly separation of the fiber can be seen from Figs. 9 and 10. Investigation of the SEM showed the fiber direction was the same direction with contact pressure. Two and six numbered samples were supported the matrix by vertical replaced fiber as a steel in concrete.

3.3. Surface Roughness

Surface roughness of samples of the wear test was given in Fig. 7. Average roughness (R_a) unit was selected for definition the roughness parameter. And the biggest roughness value was measured on which showed abrasive type wear. In this wear type poor fiber-matrix interface caused by pulled out. These pulled out fibers scratch the surface and causes the material deformation on the surface. So roughness value increased with increasing pulled out fibers. Not only the pulled out fibers caused the surface roughness but also agglomerated fibers. This condition can be seen in Fig. 8. Agglomerated or not dispersed fiber bundles give rise to bad wettability. So some of the part of the surface can be exuviate with friction force.

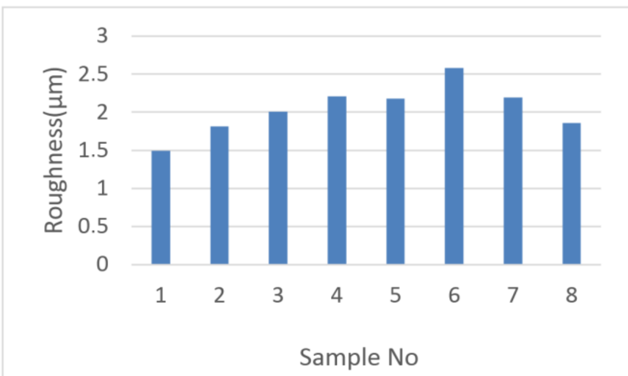

Fig. 7 Surface roughness for specimens

First sample has the finer surface roughness. It can be seen from SEM investigation from Figs. 9 and 10.

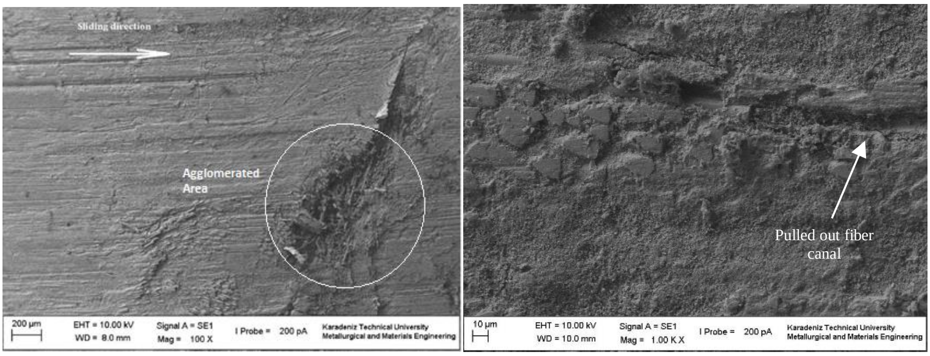

Fig. 8 a) Agglomerated fiber SEM image of the sample six (100x) b) Pulled out fiber canal of the sample four (1000x)

3.4. SEM Investigation

SEM investigations in order to determine wear mechanism of wear surface of the samples was given in Fig. 9 and Fig. 10. It can be seen wear mechanism of the samples in SEM images. Some of the image show abrasive wear but the others show adhesive wear mechanism. And replacement of the fibers (fibers angle with the surface and homogeneity) define the wearing mechanism.

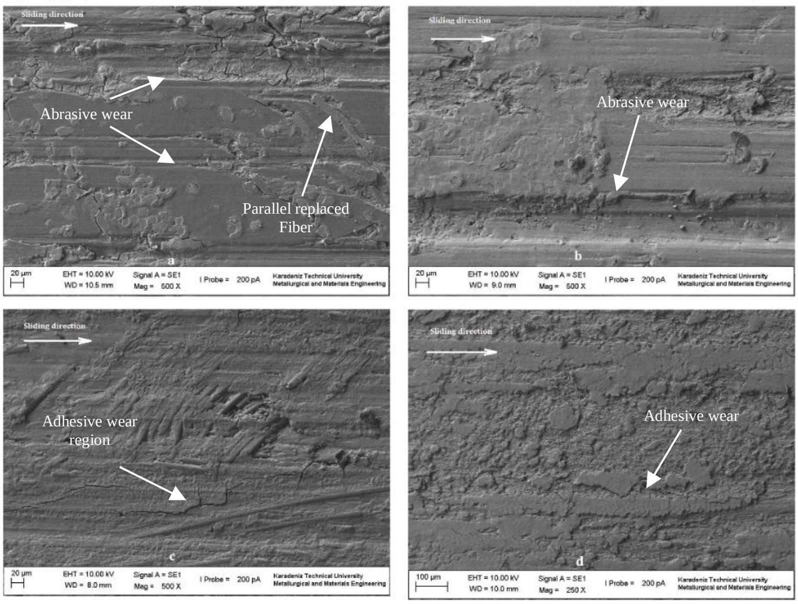

Fig. 9 SEM images of wear surface at constant pressure samples (500x) (a-1, b-2, c-3, d-4)

Fiber was removed from surface caused by abrasive wear. And roughness correlated with abrasive wear rate. So increasing abrasive wear caused to increasing roughness.

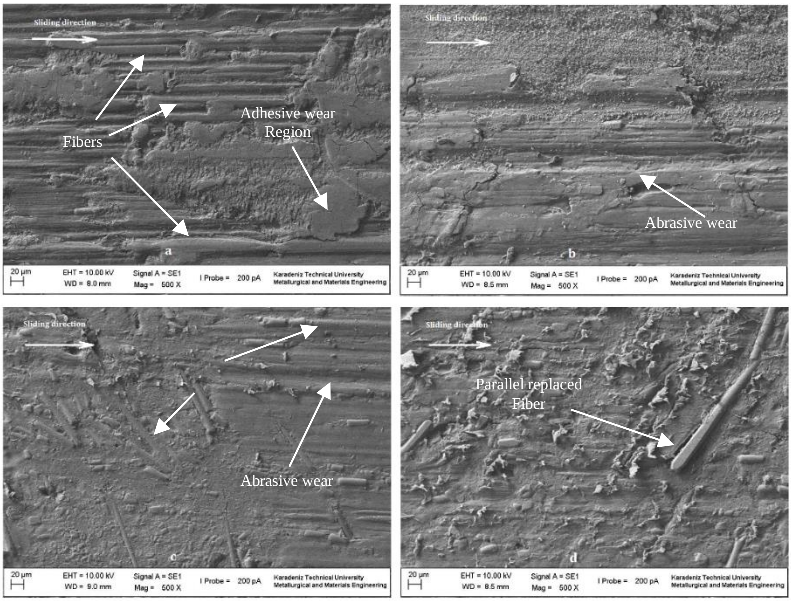

Fig. 10 SEM images of wear surface at the constant temperature samples (500x) (a-5, b-6, c-7, d-8)

Wear mechanism can affect the debris of the samples and the debris given below in Fig. 11.

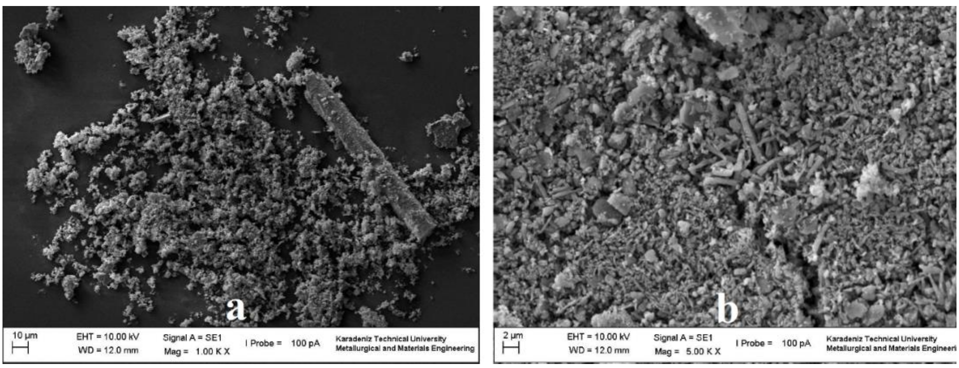

Fig. 11 SEM images of the debris of the sample seven (a-1000x, b-5000)

Powder morphology of the worn surface can reduce the friction force. Polymer debris can be transformed into the cylindrical form like rolling element. So friction force and wear rate decrease with increasing rolling element (debris). This debris can involve fibers particles too. And fibers particles can also reduce friction but it also cause to abrasive wear.

3.5. Friction Force

Average friction force diagrams were given in Fig. 12 and Fig. 13. It can be seen that reducing friction force with increasing nominal contact pressure except for fifth and seventh samples. Increasing nominal contact pressure increased temperature on the pin sliding surface. Increasing temperature caused to changing (decreasing) the visco-elastic properties of the polymers in the shear strength [18-20]. Fifth and seventh samples show increasing friction force with increasing nominal contact pressure. This phenomenon can be explaining with changing interface properties between pin and disc.[11] These samples interface properties related with fiber replacement. In other words, related with fibers contact area. Vertical replacement of the fibers to the sliding direction cause a good wear resistance with decreasing friction force or increasing surface temperature. So increasing surface temperature reduced friction force. But horizontal replacement of the fibers to the sliding surface decreases the visco-elastic properties (or temperature) on the interface with increasing fibers contact area.

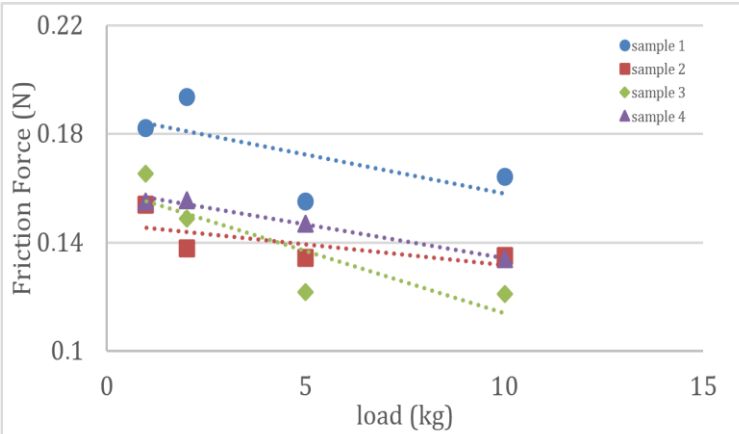

Fig. 12 Friction force versus load diagram of the constant pressure samples

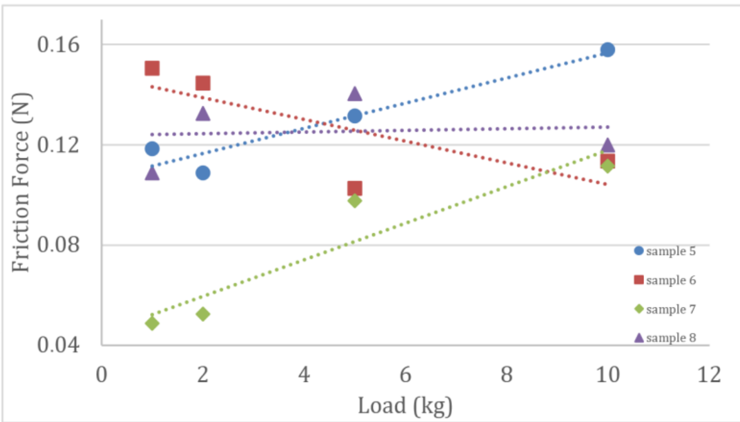

Fig. 13 Friction force versus load diagram of the constant temperature samples

When the average friction force values compared between first and second groups it can be seen a little difference caused by molding pressure. Increasing molding pressure caused decreasing friction force under a constant temperature. It can probably explain with a better wettability or mechanical bonding on fibers surface by castamide matrix. So second group's average friction force was decreased with increasing wettability. This shows the effect of molding pressure in the second group.

Amonton's first law of friction which says that the friction force is proportional to the normal force. Some wear studies [13, 21-22] on polymers showed that similar friction force changing against the first law of friction. Some of the researchers was explained this situation with chancing wear mechanisms but the others were explained with chancing thermo-mechanical properties of the thermoplastics.

4. Conclusions

In this study, E-glass reinforced cast polyamide (PA6G) was produced. And wear regime was investigated at room temperature in atmospheric condition. The following conclusions were reached.

- Low wear loss was determined due to vertical replaced fiber to the surface.
- Horizontal placement of the fibers caused to increasing of friction force.
- Poor fiber-polymer interface caused to abrasive type wear.
- All wear times show that 10 kg wear loads caused bigger wear rate almost 10 times than 5 kg loads.
- Friction force depends pin and disc interface temperature on the polymer based composites.
- Average friction force decreases with increasing molding pressure.

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