Investigation of Tribological Behaviors of Pure, Self-Lubricating and Heat Resistant Cast Polyamide Materials

Hilal CAN[1] and Engin TAN[2*]

[1, 2]Pamukkale University, Department of Metallurgical and Materials Engineering, Denizli, Turkey

*** Corresponding Author:**
E-Mail: etan@pau.edu.tr

ABSTRACT
Cast Polyamide materials are engineering plastics widely used in all types of industries due to their superior mechanical, physical, chemical and electrical properties. In the present study, the friction and wear characteristics of three different commercially available cast polyamide materials, namely pure (PA6 Standard), self-lubricating (PA6G+Lubricant) and heat resistant (PA6G+Heat Resistant), were investigated. The wear tests were carried out on a pin-disc wear setup under dry friction conditions in accordance with ASTM G132-96 standard. The tests were carried out at room temperature with a sliding speed of 1.2 m/s, sliding distances of 100, 200 and 300 m and load values of 5, 10 and 15 N. The wear performances of materials were compared in terms of weight loss and coefficient of friction. As a result of the study, it was determined that the heat resistant cast polyamide material (PA6G+Heat Resistant) has the highest wear resistance. However, it was found that wear characteristics are similar at lower loads and there are differences in wear characteristics with increasing loads.

Key Words: Cast Polyamide, Self-Lubricating, Heat Resistant, Dry Friction, Wear

1. INTRODUCTION

Cast polyamide materials have been widely used in engineering applications in recent years due to their superior properties, such as low density, low coefficient of friction, excellent wear resistance, high impact strength and high corrosion resistance [1-9]. Various studies have been carried out on the wear behaviors of cast polyamides from the beginning of 1960's and polyamides have been improved with various additives and lubricants [10-15]. Yan et al. [16] investigated the wear behavior of graphite-added PTFE composites. Palabiyik and Bahadur [17] used different polyamide 6 (PA6) blends. Bermúdez et al. [18] investigated the tribological properties of PA6 filled with molybdenum disulfide and liquid crystalline additives. Österle et al. [19] have discussed the effect of carbon fibers and silica nanoparticles on the wear behavior of polymer matrix composites. Guo et al. [20] tested the tribological mechanisms of various oxide nanoparticles in carbon fiber reinforced PEEK composites. Qi et al. [21] investigated the wear behaviors of polymer composites under ultra-dry friction and extreme dry sliding conditions. Zhang et al. [22] examined the effect of nanoparticles on the tribological behavior of conventional epoxy composites filled with carbon fiber and graphite lubricants.

Three different cast polyamide materials used in this study, namely pure (PA6 Standard), self-lubricating (PA6G+Lubricant) and heat resistant (PA6G+Heat Resistant), are used in different engineering applications according to their properties. The PA6 Standard, because of being inexpensive, functioning quietly, being lightweight, having high strength and long life, is used in the railway industry for various machine elements, such as rolling bearings and slides, bushings, spools and pulleys and gears. The PA6G+Lubricant is produced by adding additives into cast polyamide through different processes. Because of being self-lubricating, it has superior performance especially in bearing applications. Because lubrication addition is located inside pores, moisture and water intake are reduced and thus dimensional stability is ensured. The PA6G+Lubricant is used in a wide range of applications, such as ship shafts and bearings, work machine bearings, telescopic cylinder bearings, bearings in space crafts and nuclear power plants, printing machine gears, mining sector, recycling and wastewater facilities. For the PA6G+Heat Resistant, its thermal aging resistance has been significantly enhanced due to thermal stabilizer additives contained and it shows high performance at operating temperatures of 80°C and above. The PA6G+Heat Resistant is used in different engineering applications such as rolling bearings, gears, rollers, wear plates, hose outlets in water treatment plants, gears in paper production facility drying lines [23].

In this study, the tribological behaviors of three different cast polyamide materials, namelypure (PA6 Standard), self-lubricating (PA6G+Lubricant) and heat resistant (PA6G+Heat Resistant) were investigated.

2. EXPERIMENTAL STUDIES

Physical, mechanical and thermal properties of the wear test materials used in the study are shown in Table 1.

Table 1. Physical, mechanical and thermal properties of the materials used in the study

Properties	**PA6 Standard**	**PA6G+Lubricant**	**PA6G+Heat Resistant**
Specific weight (g/cm^3)	1.15	1.15	1.15
Water absorption (%)	7	5	6
Elongation at break (%)	>20	>20	>20
Tensile strength (MPa)	83	78	78
Impact strength (kJ/m^2)	5.6	6	5.6
Hardness (Shore D)	74	76	81
Melting Temperature (°C)	220	220	220
Maximum Continuous Operation Temperature (°C)	110	110	125
Short-Time Maximum Operation Temperature (°C)	170	170	185

Wear tests were carried out with a pin-disc wear test device according to ASTM G132-96 standard [24]. During tests, the surfaces of specimens were sanded with 80 grid SiC sandpaper to remove the rough surface up to 10 mm in diameter from the ACM test needle and an abrasive counterface disc (150 grid sandpaper) was used. Wear tests were carried out at sliding distances of 100, 200 and 300 m, sliding speeds of 1.2 m/s and loads of 5, 10 and 15 N. Prior to measurement, the samples were cleaned in acetone to remove surface contaminants, dried and then weighed using an electronic balance with a sensitivity of 0.001 mg. The wear test device used in the study is schematically shown in Figure 1.

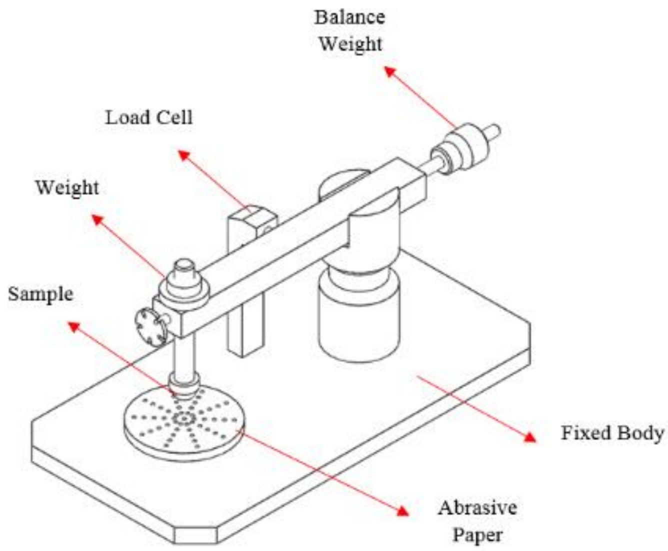

Figure 1. Pin-on disc wear-testing setup

3. RESULTS

The changes in weight loss as a function of sliding distance and load are given in Figures 2, 3 and 4 for PA6 standard, PA6G+Lubricant and PA6G+Heat Resistant materials, respectively. It is clear from Figs. 2-4 that the wear conditions significantly influence the wear behaviors of cast polyamide materials. It was observed in all specimens that weight loss significantly increased with increasing sliding distance and load. Weight losses showed a close tendency to each other at lower loads and it was determined that weight loss differences significantly increased especially at a load of 15 N. In particular, less weight loss was observed in the PA6G+Heat Resistant specimen at higher loads compared to other specimens. This reduction can be explained by high heat resistance of PA6G+Heat Resistant material and the higher hardness than other specimens.

It is seen that material type has a significant effect on weight loss, in addition to wear conditions (sliding distance, load). It was determined that the highest wear resistance was obtained in the high temperature resistant PA6G+Heat Resistant specimen. This high wear resistance value can be explained by the heat resistant transfer film formed at the wear interface. The increase in heat resistance increases the amount of wear significantly. On the other hand, the lowest wear resistance was obtained in the PA6 Standard material. This low wear resistance value can be explained by the low hardness value compared to other specimens. Unlike the pure PA6 Standard specimen, it was observed that graphite and lubricant additives in PA6G+Lubricant and PA6G+Heat Resistant materials significantly reduced the wear rate. This result completely agrees with similar literature studies [10, 15, 25-30].

The changes in coefficient of friction as a function of sliding distance and load are given in Figures 5, 6 and 7 for PA6 standard, PA6G+Lubricant and PA6G+Heat Resistant materials, respectively. The coefficient of friction is a parameter that is effectively used to characterize wear behaviors of materials. Especially, it is of great importance to investigate materials for the change in wear resistance during the wear process.

When Figures 5-7 are examined, it is seen that in all graphs there is a tendency of a similar coefficient of friction curve under similar wear conditions. It is observed that there is a significant decrease in coefficient of friction with increasing load. This reduction can be explained by a significant increase in temperature at the friction interface with increasing load, thereby significantly increasing wear. Fluctuations are observed in the coefficient of friction with sliding distance. These fluctuations are caused by the irregular loads coming to the friction interface.

The type of cast polyamide material directly affects the coefficient of friction (Figures 5-7). The highest coefficient of friction was obtained at PA6G+Heat Resistant specimen (Figure 5). The high coefficient of friction value can be explained by the higher heat resistance of the PA6G+Heat Resistant specimen. It is seen that the PA6 Standard has the lowest coefficient of friction. The low coefficient of friction is obtained in the specimen with the lowest hardness value compared with other specimens. This result can be explained by the fact that the graphite and lubricant additives form a uniform and thin transfer film layer and reduce the wear rate by increasing the coefficient of friction. These results completely agree with previous literature studies [6-7, 22, 25-33].

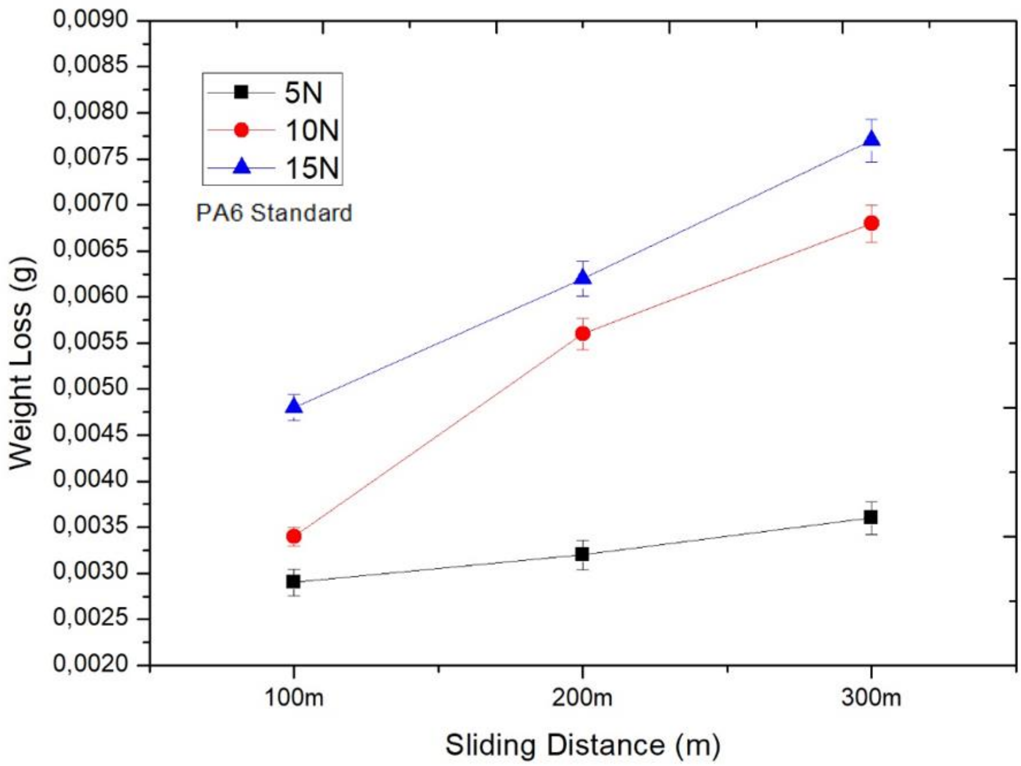

Figure 2. Weight loss change as a function of sliding distance and load for the PA6 Standard material

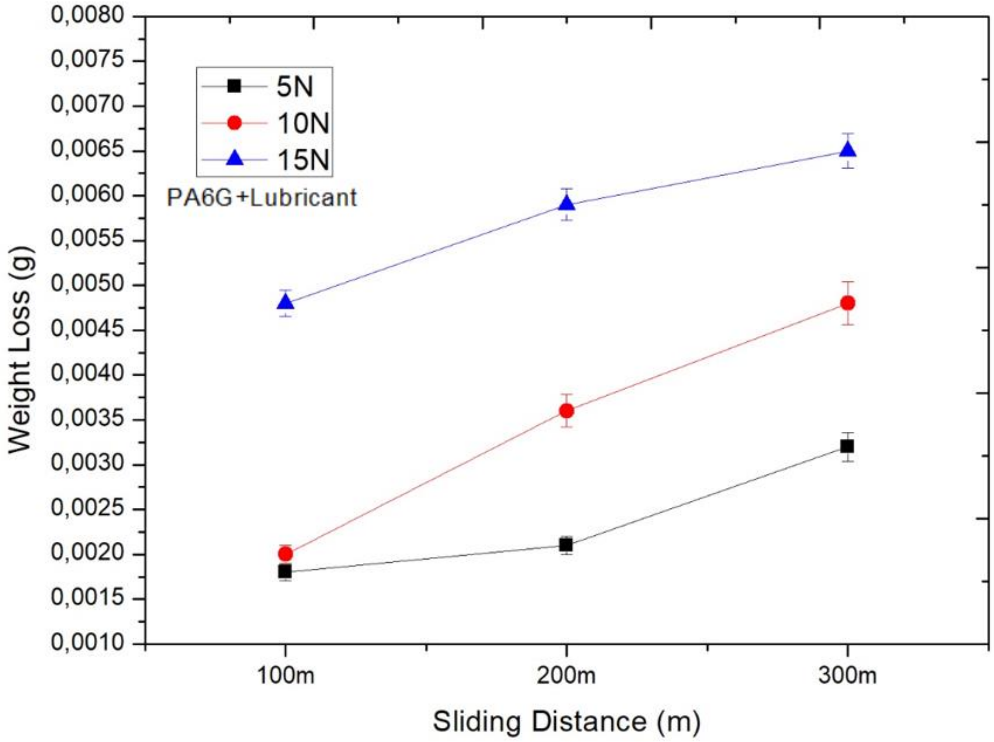

Figure 3. Weight loss change as a function of sliding distance and load for the PA6G+Lubricant material

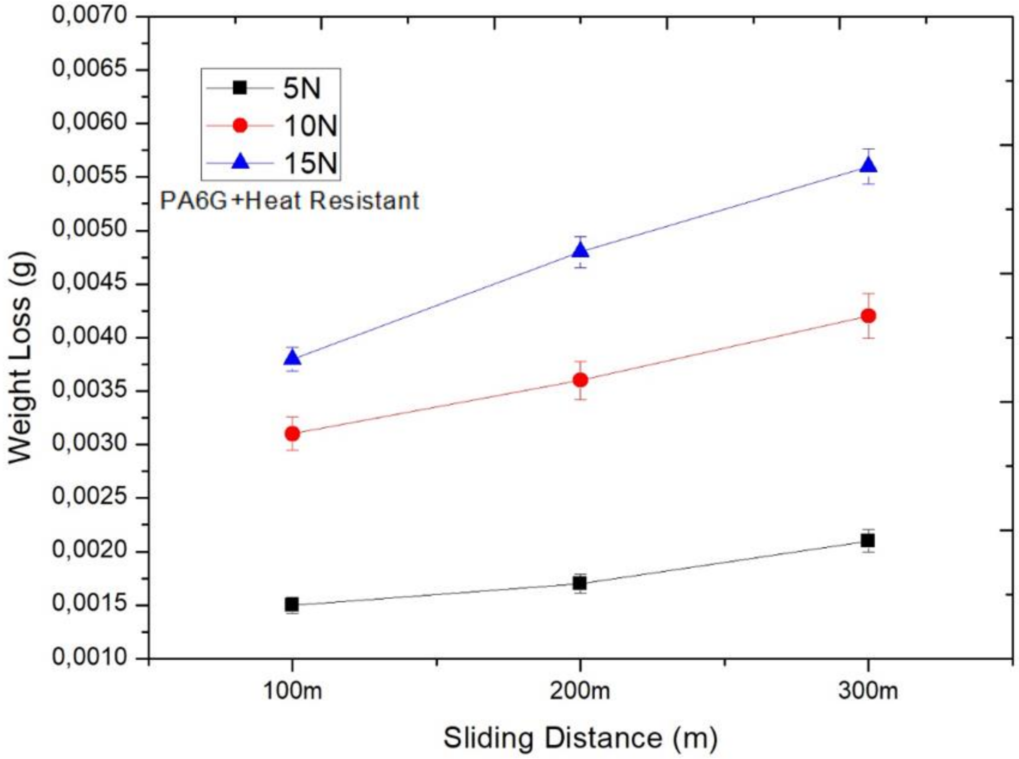

Figure 4. Weight loss change as a function of sliding distance and load for the PA6G+Heat Resistant material

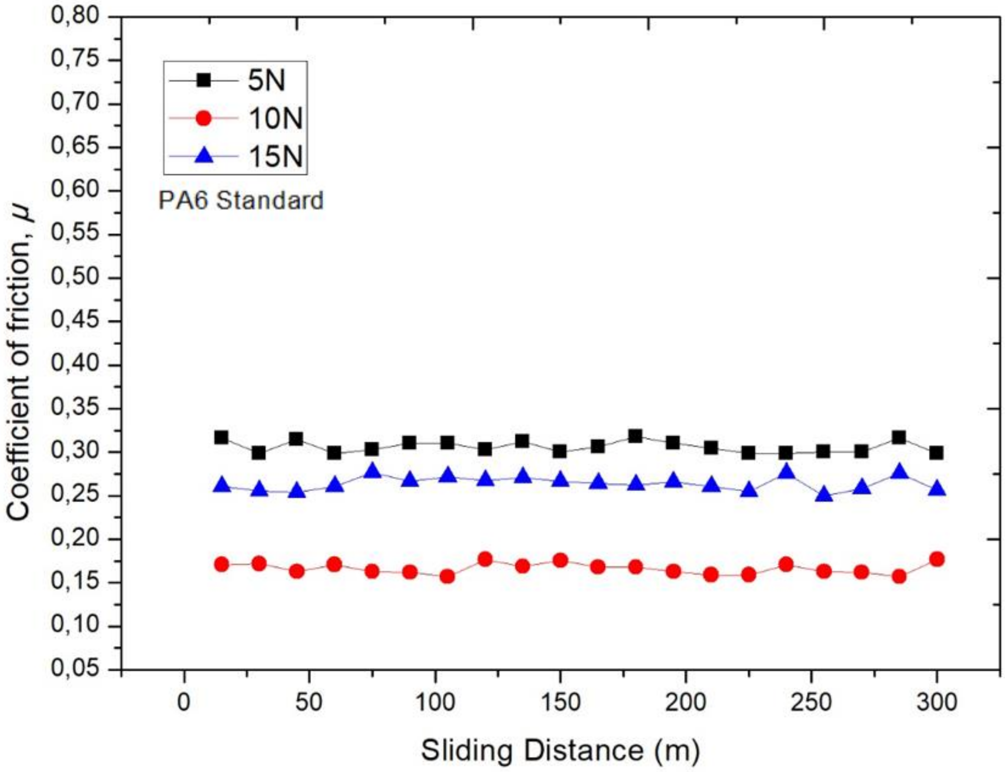

Figure 5. Change in the coefficient of friction as a function of sliding distance and load for the PA6 Standard material

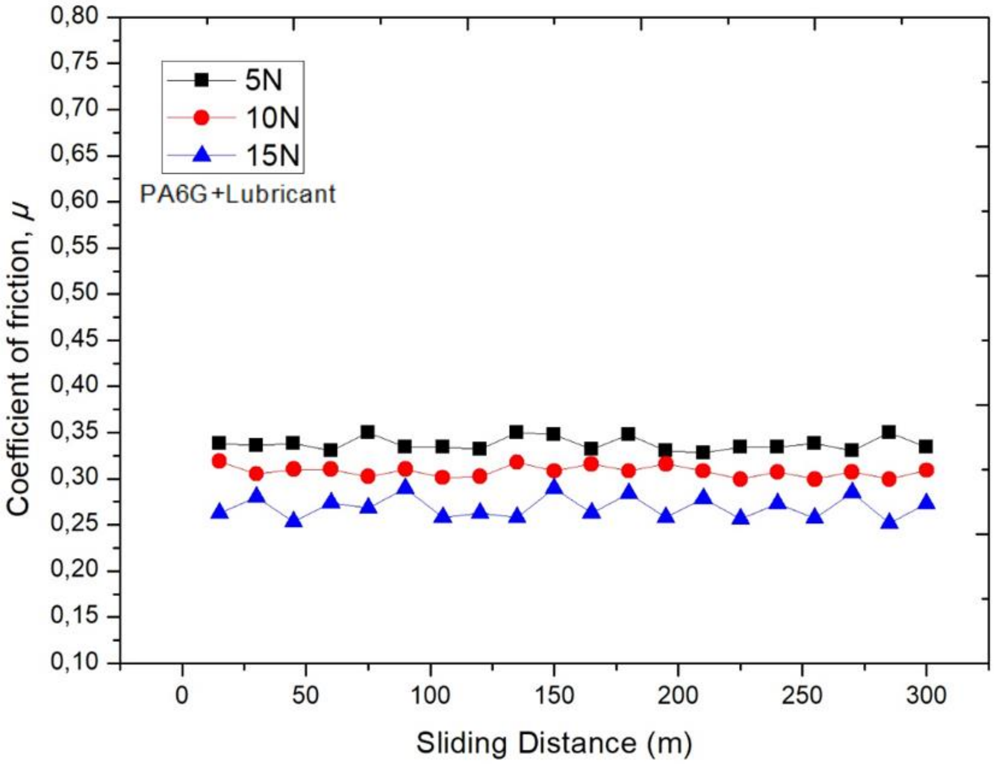

Figure 6. Change in the coefficient of friction as a function of sliding distance and load for PA6G+Lubricant material

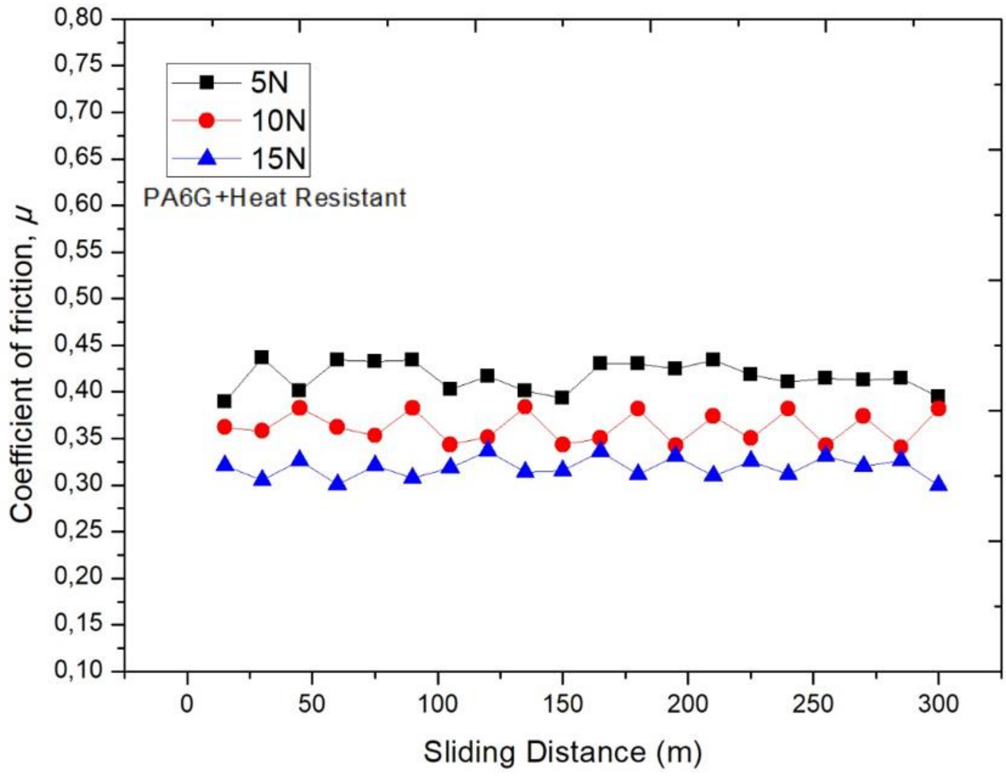

Figure 7. Change in the coefficient of friction as a function of sliding distance and load for PA6G+Heat Resistant material

4. DISCUSSION

In the present study, the tribological behaviors of various cast polyamide materials were comprehensively studied under dry sliding conditions. In this context, the following results were obtained:

- It was determined that graphite and lubricant additives added to PA6 Standard cast polyamide material improves wear resistance.
- Significant weight loss differences have been observed, especially with increasing loads, while weight losses have showed close tendency to each other at lower loads.
- It was determined that the highest wear resistance is obtained in the high temperature resistant PA6G+Heat Resistant specimen. The increase in heat resistance improves wear behaviors significantly.
- It is seen that there is a significant decrease in coefficient of friction with increasing load. This reduction is due to a significant increase in temperature at the friction interface with increasing load and consequently a significant increase in wear.
- The highest coefficient of friction is obtained at PA6G+Heat Resistant. The fact that the coefficient of friction is so high is a result of the high heat resistance of the PA6G+Heat Resistant specimen.
- It was determined that the PA6 Standard specimen has the lowest coefficient of friction. The low coefficient of friction is obtained in the specimen with the lowest hardness value compared with other specimens. According to this result, it can be said that there is a relation between coefficient of friction and hardness values.

ACKNOWLEDGMENT

The authors acknowledge Dr. İsmail Ovalı for his valuable contributions in wear tests.

REFERENCES

[1]Neis, P. D., Ferreira, N. F. ,Poletto, J. C. , Sukumaran, J., Andó, M., Zhang, Y. (2017). Tribological behavior of polyamide-6 plastics and their potential use in industrial applications.Wear 376-377, 1391–1398.

[2] Qi, H., Li G., Liu, G., Zhang, C., Zhang, G., Wanga, T., Wanga, Q. (2017). Comparative study on tribological mechanisms of polyimide composites when sliding against medium carbon steel and NiCrBSi. Journal of Colloid and Interface Science 506 415–428.

[3] Chang L., Zhang G., Wang, H., Fu, K. (2017).Comparative study on the wear behaviour of two high-temperature-resistant polymers, Tribol. Lett. 65 34–45.

[4] Song, F., Wang, Q., Wang, T. (2015). The effects of crystallinity on the mechanical properties and the limiting PV(pressure x velocity) value of PTFE, Tribol.Int. 93, 1–10.

[5] Theiler, G., Gradt, T. (2015).Tribological characteristics of polyimide composites in hydrogen environment, Tribol. Int. 92 162–171.

[6]Unal, H., Mimaroglu, A., Arda, (2006). T. Friction and wear performance of some thermoplastic polymers and polymer composites against unsaturated polyester, Appl. Sur. Scie. 252 8139–8146.

[7] Jintang, G. (2000).Tribochemical effects in formation of polymer transfer film, Wear 245 100–106.

[8] Liu, C.Z., Renb, L.Q., Tongb, J., Joyce, T.J., Green, S.M., Arnell, R.D.(2001). Statistical wear analysis of PA-6/UHMWPE alloy, UHMWPE and PA-6. Wear 249 31–36.

[9] Liu, C.Z., Wu, J.Q. Li, J.Q., Ren, L.Q., Tong, J., Arnell, R.D. (2006). Tribological behaviours of PA/UHMWPE blend under dry and lubricated condition, Wear 260 109–115.

[10] Samyn, P.,De Baets, P., Schoukens, G., Van Driessche, I. (2007). Friction, wear and transfer of pure and internally lubricated cast polyamides at various testing scales. Wear 262 1433–1449.

[11]Adams, N. (1963). Friction and deformation of nylons. J. Appl. Polym. Sci. 7, 2075–2103.

[12] Watanabe, M., Karasawa, M., Matsubara, K. (1968). The frictional properties of nylon, Wear 12 185–191.

[13] Rhee, S.H., Ludema, K.C. (1978).Mechanisms of formation of polymeric transfer films, Wear 46 231–240.

[14] Wang, J. Gua, M., Songhaob, B., Gec, S.(2003). Investigation of the influence of MoS2 filler on the tribological properties of carbon fiber reinforced nylon 1010 composites, Wear 255 774–779.

[15] Kang, S.C., Chung, D.W. (2003).Improvement of frictional properties and abrasive wear resistance of nylon/graphite composite by oil impregnation,Wear 254 103–110.

[16] Yan, F., Wang, W., Xue, Q., Long, W. J. (1996). The correlation of wear behaviors and microstructures of graphite-PTFE composites studied by positron annihilation. Appl. Polym. Sci. 61-7 1231-1236.

[17] Palabiyik, M., Bahadur, S. (2000).Mechanical and tribological properties of polyamide 6 and high density polyethylene polyblends with and without compatibilizer. Wear 246 149–158.

[18] Bermúdez, M.D., Carrion-Vilches, F.J., Martinez-Mateo, I., Martinez-Nicolas, G. (2001). Comparative study of the tribological properties of polyamide 6 filled with molybdenum disulfide and liquid crystalline additives.J.Appl.Polym.Sci.81 2426–2432.

[19] Österle, W., Dmitriev, A.I., Wetzel, B., Zhang, G., Häusler, I., Jim, B.C. (2016). The role of carbon fibers and silica nanoparticles on friction and wear reduction of an advanced polymer matrix composite, Mater. Des. 93 474–484.

[20] Guo, L.H., Qi, H.Q., Zhang, G., Wang, T.M., Wang, Q.H.(2017). Distinct tribological mechanisms of various oxide nanoparticles added in PEEK composite reinforced with carbon fibers. Compos. Part A-appl. S. 97 19–30.

[21] Qi, H.M., Zhang, G., Chang, L., Zhao, F.Y., Wang, T.M., Wang, Q.H. (2017). Ultralow friction and wear of polymer composites under extreme dry sliding conditions, Adv. Mater. Interfaces 4 1601171–1601183.

[22] Zhang, G., Sebastian, R., Burkhart, T., Friedrich, K. (2012). Role of monodispersed nanoparticles on the tribological behavior of conventional epoxy composites filled with carbon fibers and graphite lubricants, Wear 292–293 176– 187.

[23] http://www.polikim.com.tr/kestamid.asp

[24] ASTM G132 – 96 (2013). Standard test method for pin abrasion testing.

[25] Unal, H, Yetgin, S. H. (2015). The investigation of mechanical and tribological performance Of engineering polyamide polymer with solid lubricants. Duzce University Journal of Science and Technology 3 117-124.

[26] You, Y.L, XinLi D., JieSi, G., Deng, X. (2014).Investigation of the influence of solid lubricants on the tribological properties of polyamide 6 nanocomposite. Wear 311 57–64.

[27] Li, D.X., You, Y.L., DenG, X., Li, W.J., Xie, Y. (2013). Tribological properties of solid lubricants filled glass fiber reinforced polyamide6 composites, Mater.Des.46 809–815.

[28] Liu, C.Z., Wu, J.Q., Li, J.Q., Ren, L.Q., Tong, J., Arnell, A.D. (2006). Tribological behaviours of PA/UHMWPE blend under dry and lubricating condition.Wear 260 109–115.

[29] Unal, H., Mimaroglu, A. (2012). Friction and wear performance of polyamide 6 and Graphite and wax polyamide 6 composites under dry sliding conditions.Wear 289 132–137.

[30] Kang, S.C., Chung, D.W. (2000). The synthesis and frictional properties of lubricant-impregnated cast nylons. Wear 239 244–250.

[31] Yabe, T., Takajo, T., Kato, S., Ueki, F. (2000). Lubricant-supplying properties and durability of oil-impregnated polymers, Tribol. Trans. 43 453–458.

[32] Shaofeng, Z., Qiaoxin, Z., Chaoqun, W., Jin, H. (2013). Effect of carbon fiber reinforcement on the mechanical and tribological properties of polyamide6/polyphenylene sulfide composites. Materials and Design (44) 493.

[33] Chen, Y.K., Modi, O.P., Mhay, A.S., Chrysanthou, A., O’Sullivan, J.M. (2003). The effect of different metallic counterface materials and different surface treatments on the wear and friction of polyamide 66 and its composite in rolling-sliding contact. Wear 255 714–721.