EGTRIB Journal
JOURNAL OF
THE EGYPTIAN SOCIETY OF TRIBOLOGY
VOLUME 12, NO. 2, April 2015, pp. 30 - 43 ISSN 2090 - 5882

EFFECT OF HEAT TREATMENT ON THE TRIBOLOGICAL PROPERTIES OF POLYURETHANE COATINGS

Samy A. M.[1], Ibrahim R. A.[2] and Abdel-barr M. M.[3]

[1]Faculty of Engineering, Minia University, P. N. 61111, El-Minia, EGYPT.
[2]Faculty of Engineering, Beni-Suif University, Beni-Suif, EGYPT.
[3]Faculty of Engineering, Zagazig University, EGYPT.

ABSTRACT
Polyurethanes are an important component in major appliances that consumers use every day. The objective of the present work is to perform a scratch test to measure the abrasion wear resistance of polyurethane coating. Scratch test carried out to investigate the friction coefficient and abrasive wear resistance respectively.

The experiments were carried out by heated test specimens to 80, 90, 100 and 110 °C for 5 and 10 minutes then cooled in air and furnace. Wear resistance can be obtained by measuring the wear scar width. The friction force measure from load cell and the normal load measure by dead weight. The applied load values were 2, 4, 6, 8 and 10 N.

Test results show that, the minimum values of friction coefficient observed for polyurethane coating heated to 90 °C for 5 minutes cooled in air. The maximum values of friction coefficient showed by specimens which heated to 90 °C for 5 minutes and cooled in furnace. Wear of polyurethane coatings decreased as the cooling rate decreased. The heat treatment process of polyurethane coating showed significant effect on the wear resistance. Polyurethane coating heat treated to 100 °C for 5 minutes and cooled in furnace showed the higher wear resistance.

KEYWORDS
Wear resistance, friction coefficient, heat treatment, Polyurethane coating, and Scratch test.

INTRODUCTION
The flooring coated by Polyurethanes can be described as more durable, easier to maintain and more aesthetically pleasing product. For the carpet in residential or commercial applications using of flexible polyurethane foam as a carpet underlay significantly increase the lifespan of the carpet, protect its appearance, provide additional comfort and support and reduce of ambient noise.

Tribological and surface mechanical properties of materials can be studied by means of Scratch test. It is a great value for both academic and industrial communities to understanding of this test, [1 – 4]. "The scratch hardness and the surface deformation mechanisms of materials depend in particular on the tribology of the material, the indenter geometry and the friction at the interface". Several experimental and

numerical studies of the scratch test performed on metals and polymers were conducted to describe the scratch mechanism and to investigate whether or not important; scratch quantities can be determined with sufficient accuracy from standard scratch experiments, [5]. "The mechanism of scratching was divided into two different types. The first one was termed as mild scratching for tough materials, while the second type, termed as severe scratching, for materials of relatively low toughness", [6].

Finite element methods were introduced as a numerical approach for modeling the scratch test, [7]. Briscoe et al., concluded that "there is a representative level of plastic strain of approximately 35% at frictionless scratching", [8]. There are some parameters such as scratch depth and time dependence of polymeric materials may complicate the evaluations of the experiments when performing scratch experiments. A linear relation between the applied forces, the scratch width and the scratch depth was introduced by Akono and Ulm, [9].

The relation was validated using experimental scratch data on cement paste and sandstone, which showed that the proposed approach provided a convenient way to determine the fracture toughness from scratch tests carried out with different scratch widths and depths. Nano-scratch and nano-fretting tests were performed on highly polished biomedical grade Ti6Al4V, 316L stainless steel and Co Cr alloy samples using a 3.7 μm sphero-conical diamond indenter in a commercial nano-mechanical test system (NanoTest), [10]. "Over a wide range of experimental conditions the Co Cr alloy showed significantly better wear resistance". In order to understand the failure mechanism of artificial joints it is necessary to understand the mechanism that governs roughening of metallic surface and subsequent damage nucleation and wear at the bearing interface. Najjer et al. recorded that scratching of the metallic surface by entrapped wear debris leading to increased polyethylene wear rates has been recognized as one of the main causes of early failure of total joint replacement, [11]. It has been suggested by Li and co-workers that current biomedical materials do not provide adequate load support, [12].

Scanning electron microscopy analysis of the retrieved Co Cr heads has been performed, [13], showing four different types of third-body related damage. It was demonstrated that if a scratch of certain size is created over the shot peened surface then the benefit can be reduced or even completely eliminated. The fatigue life and non-propagating cracks of scratch damaged shot peened components were predicted, [14 - 16]. A good agreement was found between the numerical predictions and experimental results. Some concern arises if the treated surface is damaged in some way, for example by a scratch. Using of scratch testing to measure the adhesion strength of calcium phosphate (CaP) coatings that were applied to a poly(carbonate urethane) (PCU) substrate by an aqueous process at temperatures of 19, 28, 37, and 50 ◦C were investigated, [17]. Cetinkaya carried out a critical studies and examinations of friction due to scratching of tungsten diselenide (WSe2) film, [18].

The scratch test is most likely the oldest conception of a mechanics-of-materials test for property characterization. It suffices to recall the Mohs scale of mineral hardness which rationalized, in 1812, the scratch resistance into a quantitative metric for the classification of various minerals' [19]. Scratching with real grain is different from scratching with prefect indenter. With the same conditions, the grain cut less material than a perfect indenter. The irregularity and the roughness of the real grain as well as the loading of the grain wedges by wear debris are eventually responsible of this

phenomenon. In belt finishing, a suitable lubrication could limit this phenomenon. – A thigh speed scratching with areal grain, which better approach the reality of belt finishing, more severe plastic deformation has been observed that at low speed. The wear mode is a plowing with a transition to cutting, [20]. Strain rate increases which increase the flow stress of the material. Furthermore, each cutting edge of the grain behaves as an isolated indenter which leads to produce several parallel scratches on the soft surface.

In the present work, the effect of heat treatment on the friction coefficient and wear resistance of polyurethane coatings is investigated. Polyurethane coatings were heated to different temperatures then cooled in air and furnace.

EXPERIMENTAL

The test rig, used in the experiments was top scratching tester equipped with an indenter to produce a scratch on a flat surface with a single pass. The details of the test rig are shown in Figs. 2, 3. The indenter, used in experiments, was a square insert (12 × 12 mm) of TiC with tip radius of 0.1 mm and hardness of 2800 kp/mm2. The scratch force was measured by the deflection of load cell. The ratio of the scratch force to the normal force was considered as friction coefficient. Wear was considered in form of wear scar width of the scratch. The applied load values were 2, 4, 6, 8 and 10 N. The arrangement of the test rig is shown in Fig. 1.

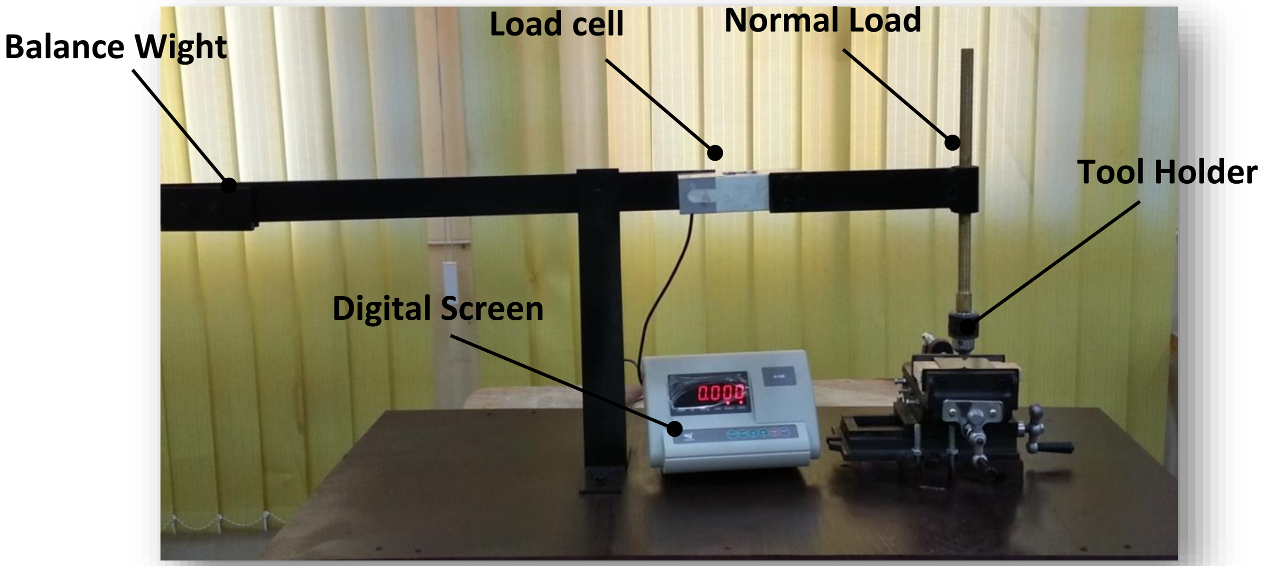

Fig. 1 Arrangement of the friction tester.

The test specimens were prepared in the form of flat sheets (60 mm × 60 mm × 2 mm) coated by polyurethane with thickness of 0.5 mm as shown in figure 1. Test specimens were prepared by coated the metallic sheets by polyurethane then waited for 30 hours for complete solidification. After complete solidification the heat treatment processes were carried out. The test specimens show in Fig. 2.

The experiments were carried out by heated test specimens to 80, 90, 100 and 110 °C for 5 and 10 minutes then cooled in air or furnace. Wear resistance can be obtained by measuring the wear scar width. The friction force measure from load cell and the normal load measure by dead weight. The applied load values were 2, 4, 6, 8 and 10 N. the arrangement of scratch tool and specimens show in Fig. 3.

Fig. 2 Polyurethane test specimens.

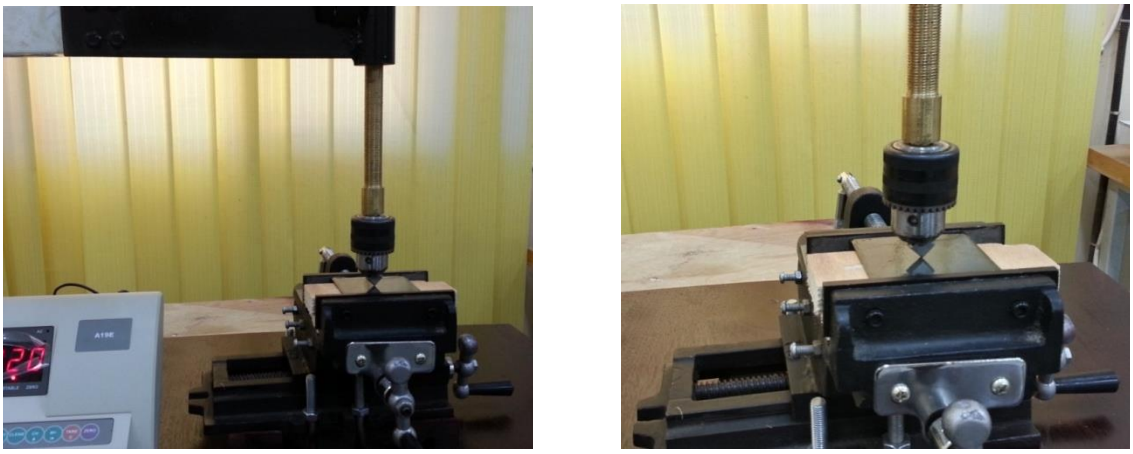

Fig. 3 Arrangement of scratch tool and specimens.

RESULTS AND DISCUSSION

The results of the friction coefficient displayed by the tested specimens are shown in Figs. 4 - 11. Figure 4 shows the relation between friction coefficient and normal loads for polyurethane coating heated to 80 °C for 5 minutes. It can be noticed that the friction coefficient increases with increase of normal load. Friction coefficient remarkably decreases with increase of cooling rate. This behaviour confirms that the test specimens possessed relatively higher hardness than the other ones. The reduction of friction coefficient may be due to the increase of the coating hardness which means significantly increases in coating shear strength so the scratching tool could not penetrate deeply in the test specimens.

Friction coefficient of polyurethane coating, heated to 80 °C for 10 minutes is shown in Fig.5. Increasing time of heat treatment showed slightly decreasing in friction coefficient values. The reduction in friction is due to the increase of plastic deformation of the polymer causing significant decrease in shear strength. Maximum values of friction coefficient were observed for non treated test specimens under 10 N applied load.

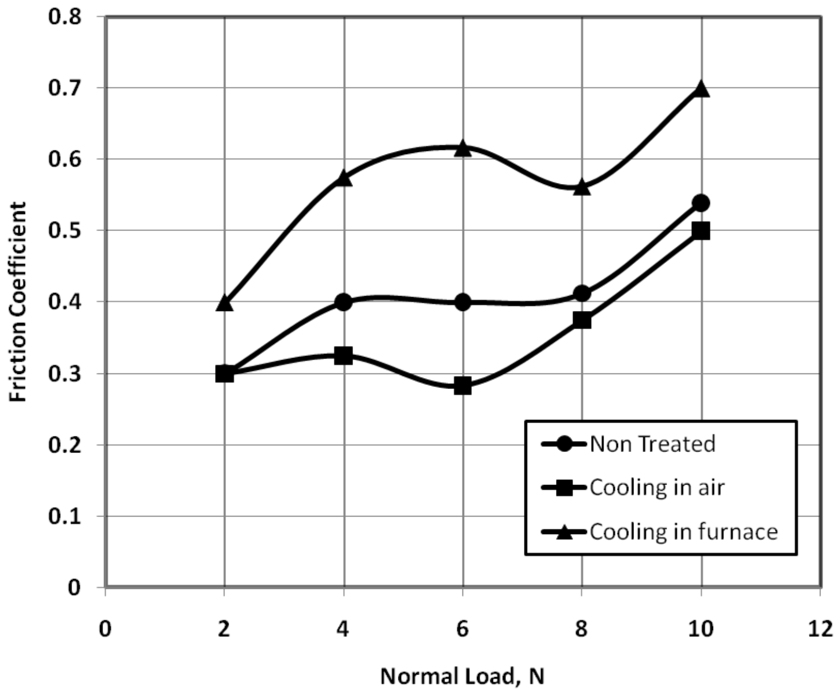

Fig. 4 Friction coefficient of polyurethane coating at 80 ˚C and 5 minutes.

.

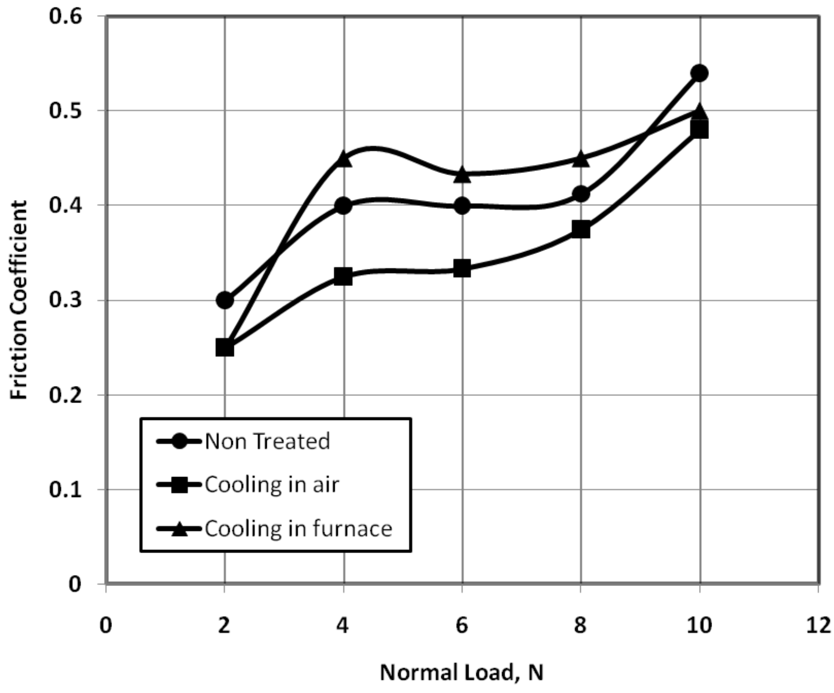

Fig. 5 Friction coefficient of polyurethane coating at 80 °C and 10 minutes.

Friction coefficient of polyurethane coating, heated to 90 °C for 5 minutes shown in Fig. 6. Friction coefficient remarkably decreases with increase of temperature. Maximum value of friction coefficient observed for specimens cooled in furnace under 10 N applied loads, the minimum value of friction coefficient observed for specimens cooled in air under 2 N normal load.

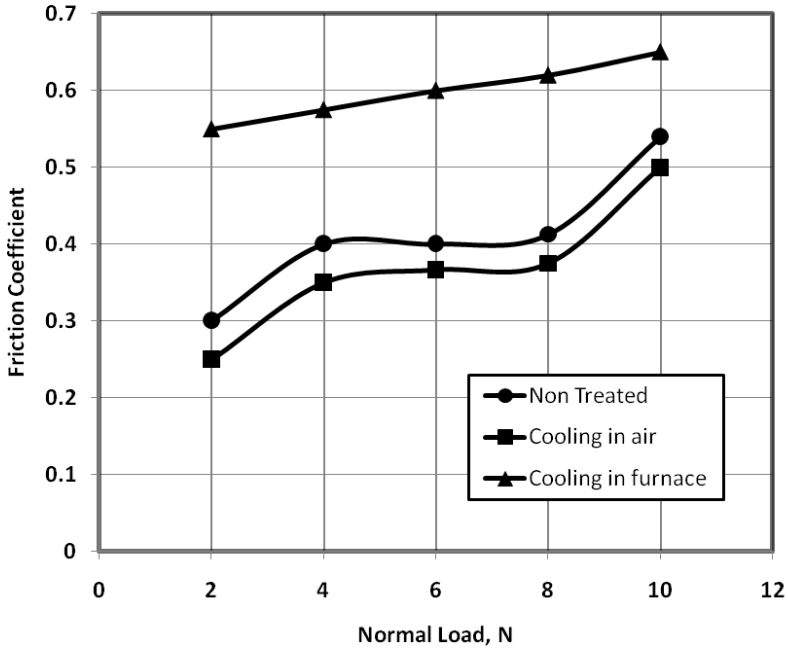

Fig. 6 Friction coefficient of polyurethane coating at 90 °C and 5 minutes.

Figure 7 shows the relation between friction coefficient and normal loads for polyurethane coating heated to 90 °C for 10 minutes. It can be noticed that the friction coefficient increase with increasing normal load. Increasing heat treatment time show the significant decreasing in friction coefficient values. This behavior may be related to more homogenous of coating and increasing of hardness of coating surface. The minimum value of friction coefficient displayed by test specimens cooled in air and 2 N normal load.

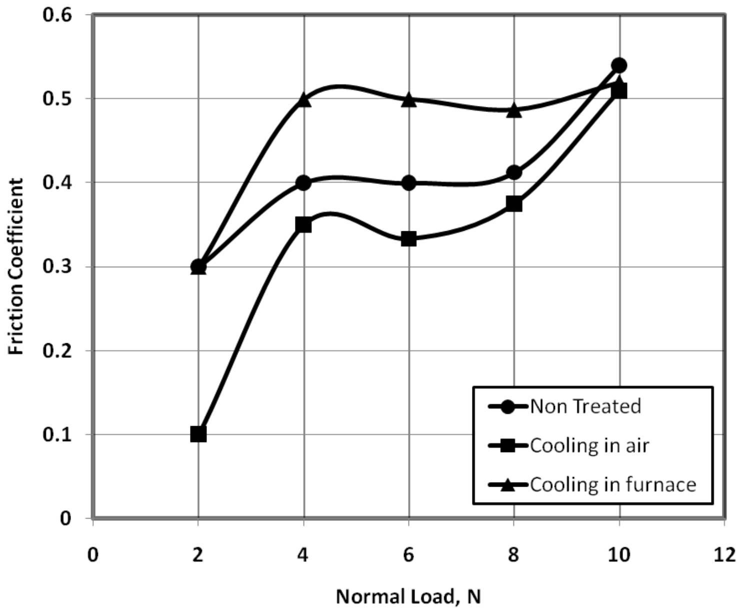

Fig. 7 Friction coefficient of polyurethane coating at 90 °C and 10 minutes.

It can be noticed that the friction coefficient of Polyurethane coatings heated to 100 °C for 5 and 10 minutes respectively; increase with increasing normal loads-figs. 8, 9. The results of air cooling shows the increase of friction coefficient values compared to non-treated specimens. Friction coefficient slightly decreased with increasing temperature of the heat treatment time. The specimens cooled in furnace shows the lower value of friction coefficient. The minimum value of friction coefficient was (0.15) observed for specimens cooled in furnace under 2 N normal load.**

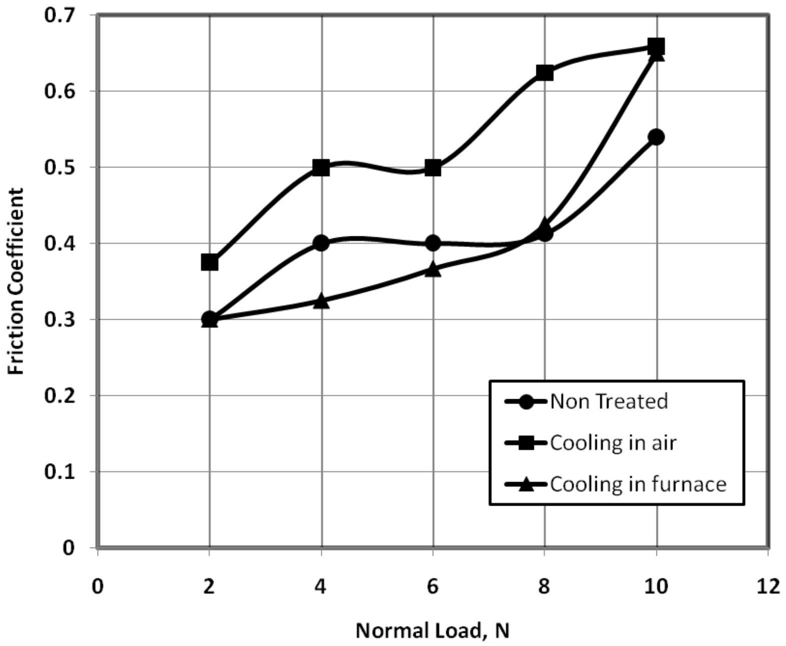

Fig. 8 Friction coefficient of polyurethane coating at 100 °C and 5 minutes.

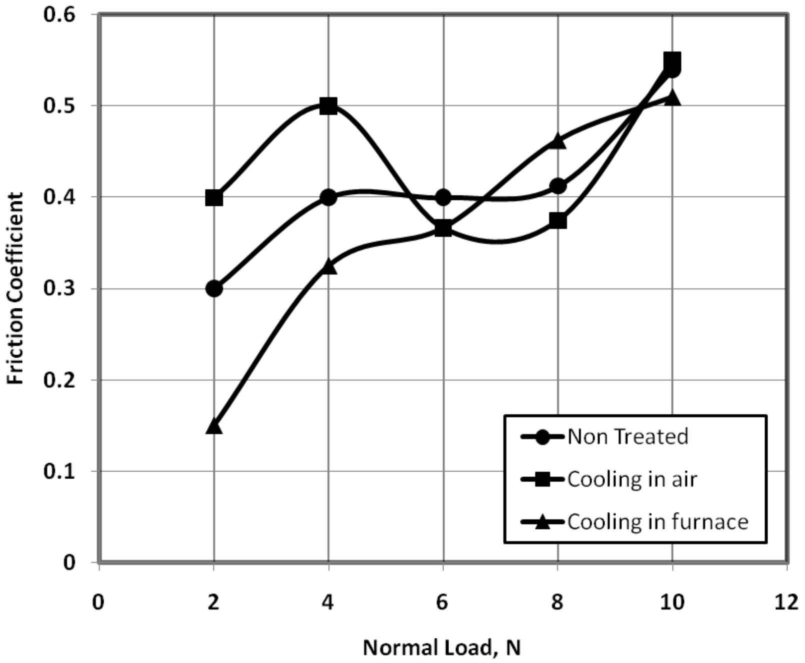

Fig. 9 Friction coefficient of polyurethane coating at 100 °C and 10 minutes.

Figure 10 shows the relation between friction coefficient and applied normal loads for polyurethane coating heated to 110 °C for 5 minutes. It can be noticed that the friction

coefficient increased with increasing normal loads for specimens cooled in furnace and non treated test specimens. The specimens cooled in air showed random behavior.

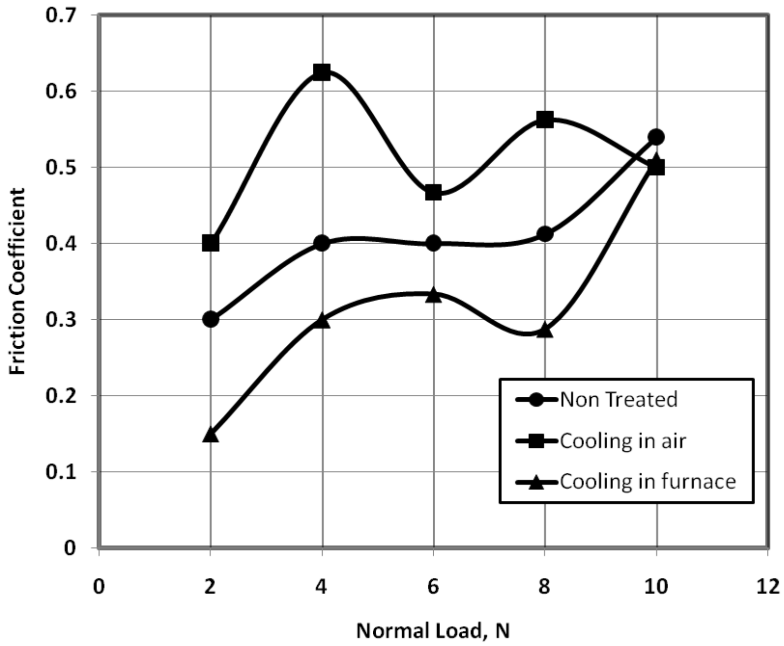

Fig. 10 Friction coefficient of polyurethane coating at 110 °C and 5 minutes.

Figure 11 shows the relation between friction coefficient and normal loads for polyurethane coating heated to 110 °C for 10 minutes. It can be noticed that the friction coefficient increased with increasing normal loads. The heat treatment at 110 °C and 10 minutes showed insignificant effect on the values of friction coefficient.

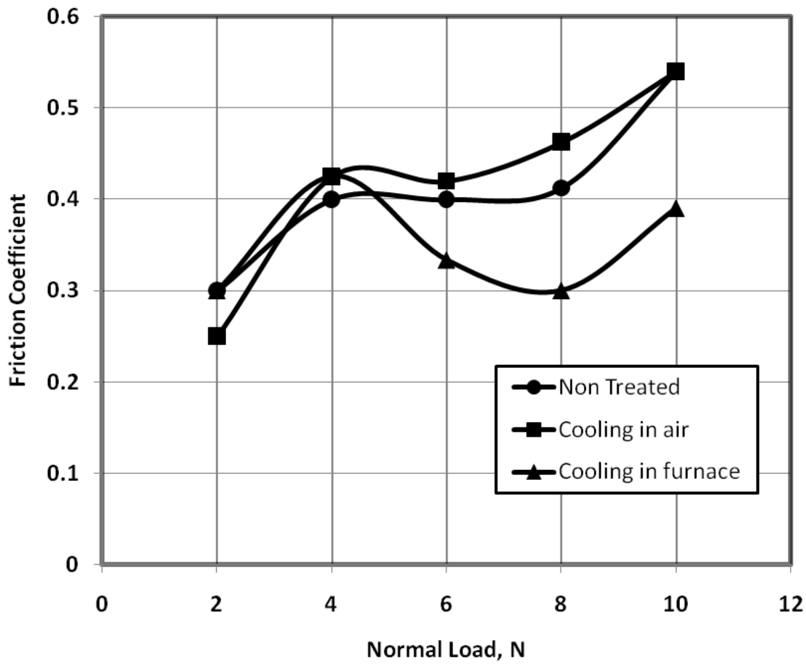

Fig. 11 Friction coefficient of polyurethane coating at 110 °C and 10 minutes.

The results of the friction coefficient displayed by the tested specimens are shown in Figs. 12 – 19. Wear of polyurethane coating test specimens versus applied load at 80 °C and 5 minutes is shown in Fig. 12. Wear increased with increasing applied load. The furnace and air cooled test specimens showed wear values lower than that presented by non-treated specimens. The lowest value of wear scar width was observed for specimens cooled in air.

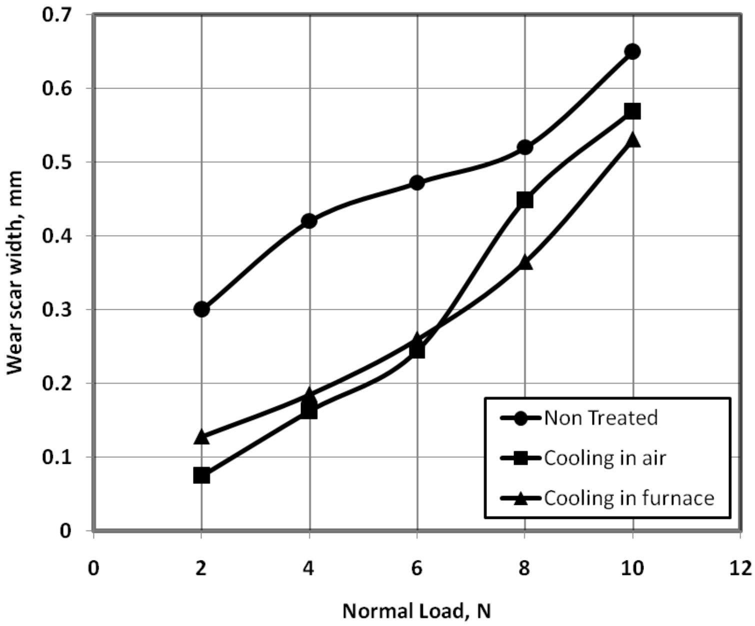

Fig. 12 Wear scar width of polyurethane coating at 80 °C and 5 minutes.

Figure 13 shows the relation between wear scar width and normal loads for polyurethane coating heated to 80 C° for 10 minutes. It can be noticed that the wear scar width increased with increasing normal load. The specimens cooled in furnace showed the lowest wear values compared to the non-treated specimens. This behavior may be related to the increase of deformation in coating layer.

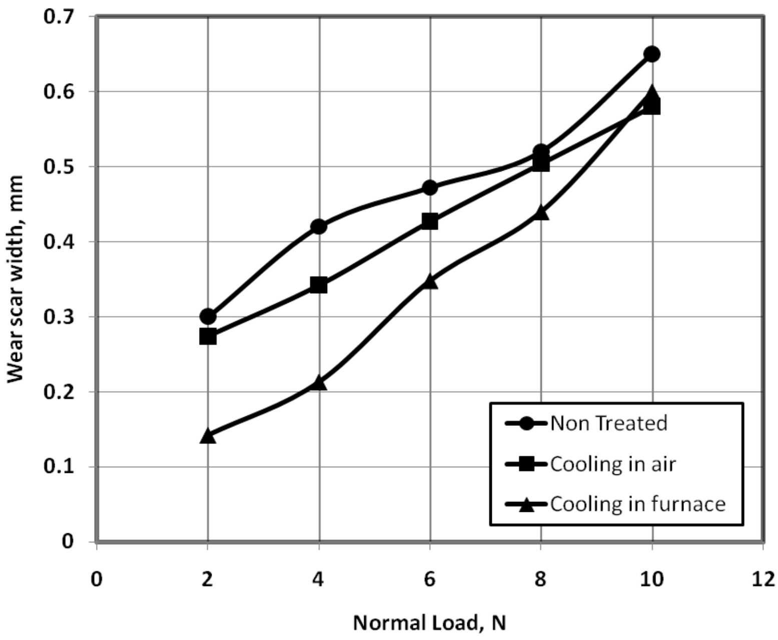

Fig. 13 Wear scar width of polyurethane coating at 80 °C and 10 minutes.

Figure 14 showed the relation between wear scar width and normal loads for polyurethane coating heated to 90 °C for 5 minutes. It can be noticed that the same behavior of test specimens heated to 80 C° and 10 minutes. This observation may be related to the insignificant effect of heating temperature on the resistance of coating to wear.

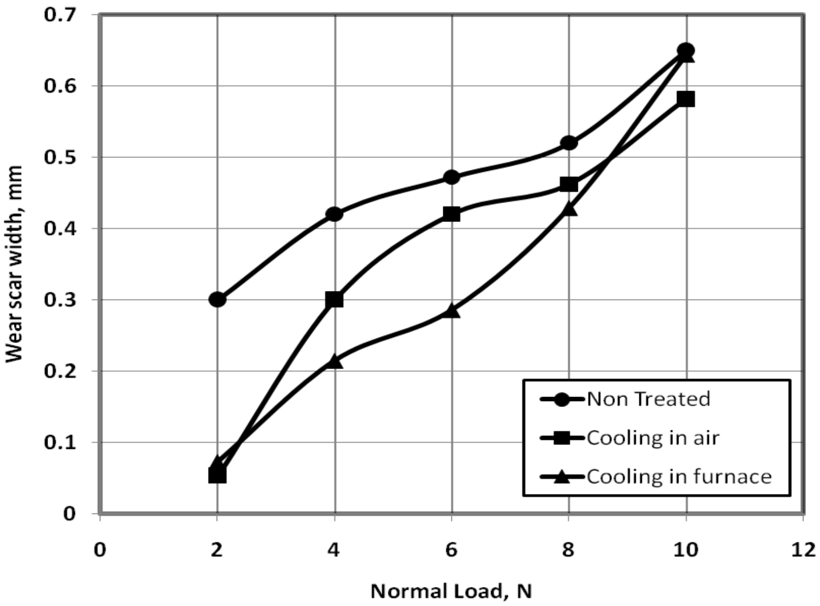

Fig. 14 Wear scar width of polyurethane coating at 90 °C and 5 minutes.

Figure 15 shows the relation between wear scar width and normal loads for polyurethane coating heated to 90 °C for 10 minutes. It can be noticed that the specimens cooled in air showed the lowest values of wear scar width. This behavior may be related to increase of the hardness of test specimens and the increase the resistance of coating material to scratch. The minimum values of wear were observed for specimens cooled in air.

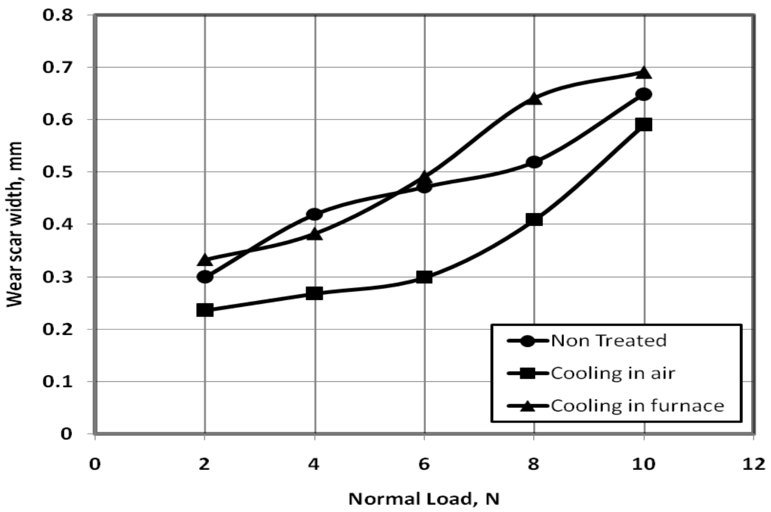

Fig. 15 Wear scar width of polyurethane coating at 90 °C and 10 minutes.

Figure 16 shows the relation between friction coefficient and normal loads for polyurethane coating heated to 100 °C for 5 minutes. It can be noticed that there is a significant reduction in wear scare width which may be related to increase of abrasive resistance of coating. The specimens cooled in furnace showed the lowest values of wear scar width. It can be recommended that the specimens cooled in furnace for industrial applications.

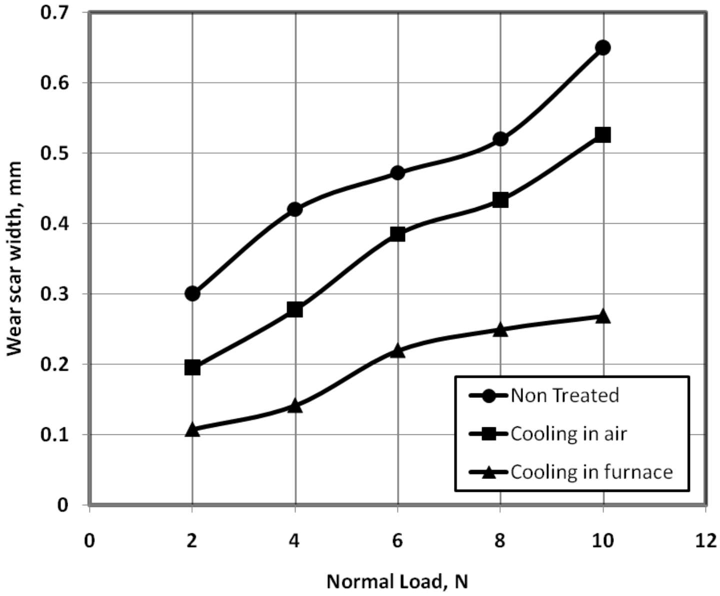

Fig. 16 Wear scar width of polyurethane coating at 100 °C and 5 minutes.

Figure 17 shows the relation between wear scar width and normal loads for polyurethane coating heated to 100 C° for 10 minutes. The heat treatment of polyurethane coating showed significant wear resistance. The values of wear scar width increase with increasing normal load. The minimum values of wear scar width were observed for specimens cooled in air under 2 N normal load.

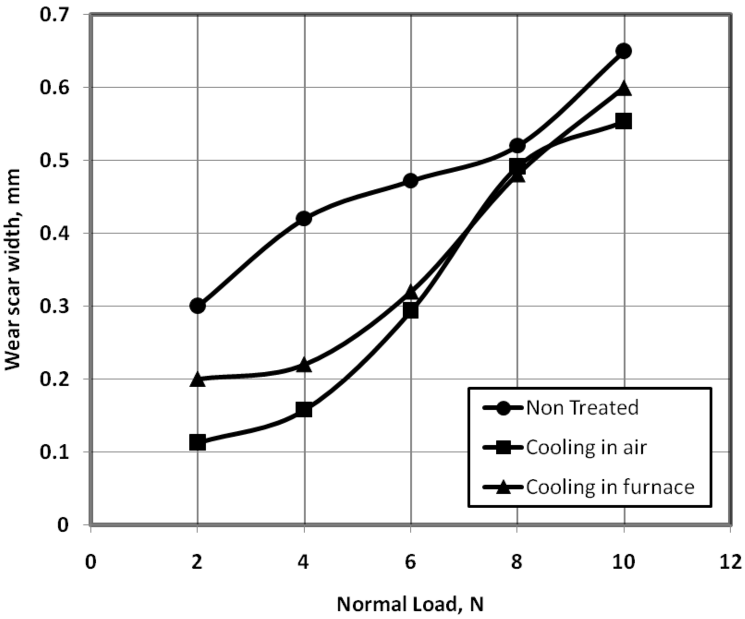

Fig. 17 Wear scar width of polyurethane coating at 100 °C and 10 minutes.

Wear scar width of polyurethane coating heated to 110 °C for 5 minutes versus with normal load shown in Fig. 18. The heat treatment process shows significant effect on increasing abrasion resistance of coating. This behavior may be related to the increasing hardness of polyurethane. The cooling rate showed no effect on wear resistance.

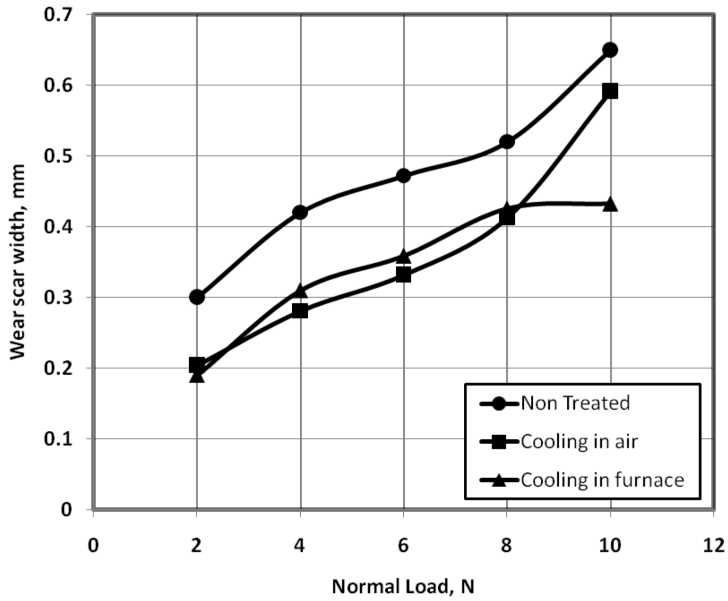

Fig. 18 Wear scar width of polyurethane coating at 110 °C and 5 minutes.

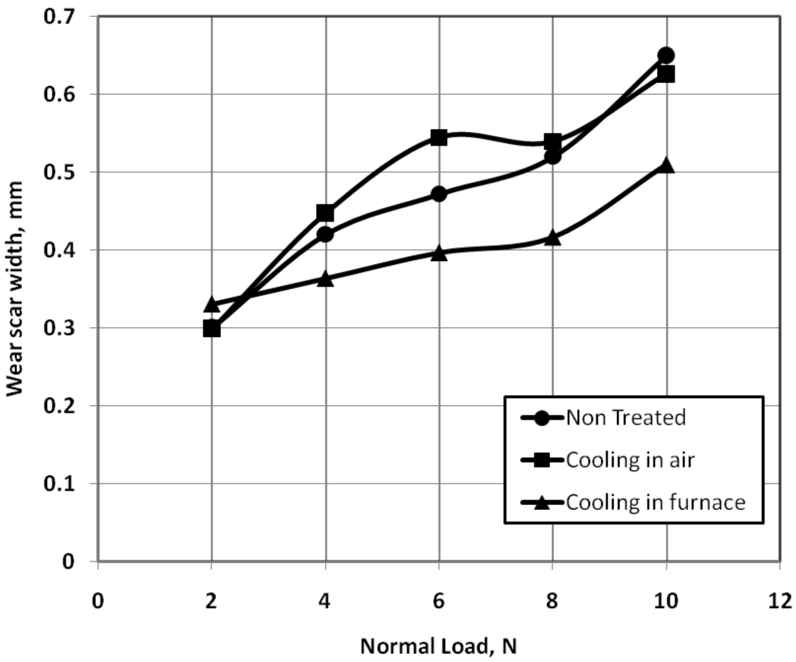

Fig. 19 Wear scar width of polyurethane coating at 110 °C and 10 minutes.

Figure 19 shows the relation between wear scar width and normal loads for polyurethane coating heated to 110 °C for 10 minutes. It can be noticed that increasing of wear scar width with increase of normal loads. The specimens cooled in air showed higher values of wear scar width. This behavior may be related to increasing of

brittleness of polyurethane coating. The coating became weaker to resist the abrasion action of polyurethane. The specimens cooled in furnace showed the lowest values of wear scare width.

CONCLUSIONS

1- **The minimum values of friction coefficient were observed at polyurethane coating heated to 90 °C for 5 minutes and cooled in air.**
2- **The maximum values of friction coefficient were shown by specimens heat treated at 90 °C for 5 minutes and cooled in furnace.**
3- **Wear of polyurethane coatings decreased as the cooling rate decreased.**
4- **The heat treatment process of polyurethane coating showed significant effect on the wear resistance.**
5- **Polyurethane coating heat treated at 100 °C for 5 minutes and cooled in furnace showed the high resistance against abrasion wear.**

REFERENCES

1. Jardret V., Zahouani H., Loubet J. L., Mathia T. G., "Understanding and quantification of elastic and plastic deformation during a scratch test", Wear 218, pp. 8 - 14, (1998).
2. Felder E., Bucaille J. L., "Mechanical analysis of the scratching of metals and polymers with conical indenters at moderate and large strains", Tribology International 39, pp. 70 - 87, (2006).
3. Gauthier C., Durier A.-L., Fond C., Schirrer R., "Scratching of a coated polymer and mechanical analysis of a scratch resistance solution", Tribology International 39, pp. 88 - 98, (2006).
4. Ali W. Y. and Mahmoud M., "Abrasive Wear of Polymeric Composites", Journal of the Egyptian Society of Tribology, Vol. 6, No. 4, October 2009, pp. 50 - 59, (2009).
5. Wredenberg F. and Larsson P. L., "Scratch testing of metals and polymers: Experiments and numerics", Wear 266, pp. 76 – 83, (2009).
6. Xie Y. and Hawthorne H. M., "A controlled scratch test for measuring the elastic property, yield stress and contact stress–strain relationship of a surface", Surface and Coatings Technology 127, pp. 130 – 137, (2000).
7. Wredenberg F. and Larsson P. L., "On the numerics and correlation of scratch Testing", Journal of Mechanics of Materials and Structures 2, pp. 573 – 594, (2006).
8. Briscoe B. J., Evans P. D., Biswas S. K. and Sinha S. K., The hardness of poly(methylmethacrylate), Tribology International 29, pp. 93 - 104, (1996).
9. Akono A. T., Ulm F. J., "Scratch test model for the determination of fracture toughness", Engineering Fracture Mechanics 78, pp. 334 - 342, (2011).
10. Liskiewicz T. W., "Comparison of nano-fretting and nano scratch tests on biomedical materials. Tribology International (2012), http: // dx.doi.org /10.1016/ j.triboint. 2012. 08. 007.
11. Najjer D., Behnamghader .A, Iost A., Migaud H., "Influence of a foreign body on the wear of metallic femoral heads and polyethylene acetabular cups of total hip prostheses", Journal of Materials Science, 2000, 35, pp. 4583 - 4588, (2000).
12. Li X., Wang X., Bondokov R., Morris J., An Y. H., Sudarshan T. S., "Micro/nanoscale mechanical and tribological characterization of SiC fo orthopaedic applications", Journal of Biomedical Materials Research Part B, (Applied Biomatererials), 72B, pp. 353 - 61, (2004).
13. Raimondi M. T.,Vena P., Pietrabissa R., "Quantitative evaluation of the prosthetic head damage induced by microscopic third-body particles in total hip replacement",

Journal of Biomedical Materials Research Part B, (Applied Biomatererials), 58, pp. 436 - 448, (2001).
14. Cláudio R. A., Silva J. M., Branco C. M. and Byrne J., "A fracture mechanics based approach to predict fatigue life of scratch damaged shot peened components", Procedia Engineering 10, pp. 2672 - 2677, (2011).
15. Benedetti M., Fontanari V., Santus C., Bandini M., "Notch fatigue behaviour of shot peened high-strength aluminium alloys: Experiments and predictions using a critical distance method", I J of Fatigue, 2010, 32, pp. 1600 - 1611, (2010).
16. Cláudio R. A., Silva J. M., Branco C. M., Byrne J., "The ability of current models for fatigue life prediction of shot peened components", Key Eng Mat, pp. 417 – 418, pp. 901 - 904, (2010).
17. Barnes D., Johnson S., Snell R. and Best S., "Using scratch testing to measure the adhesion strength of calcium phosphate coatings applied to poly(carbonate urethane) substrates", Journal of the Mechanical Behavior of Biomedical Materials, 6, pp. 128 -138, (2012).
18. Cetinkaya K., "An effect of feeding system on the scratches of sheet metal strips", Materials and Design 28, pp. 362 - 367, (2007).
19. Broz M. E., Cook R. F., Whitney D. L., "Microhardness, toughness and Mohs scale minerals", Am Mineral 91, pp. 35 – 42, (2006).
20. Khellouki A., Rech J., Zahouani H., "Micro-scale investigation on belt finishing cutting mechanisms by scratch tests", Wear 308, pp. 17 – 28, (2013).