EGTRIB Journal
JOURNAL OF
THE EGYPTIAN SOCIETY OF TRIBOLOGY
VOLUME 14, No. 1, January 2017, pp. 40 – 50 ISSN 2090 - 5882

FRICTION BEHAVIOR OF HYBRID COMPOSITES FILLED BY TITANIUM DIOXIDE NANOPARTICLES

Meshref A. A., Mazen A. A., El-Giushi M. A. and Ali W. Y.

Department of Production Engineering & Design, Faculty of Engineering, Minia University, EGYPT.

ABSTRACT
The objectives of the present work are to evaluate the effect of curing times, titanium dioxide nanoparticles and normal loads on the friction coefficient of hybrid composite resin filled by titanium dioxide nanoparticles. Four sets of composite resin specimens are prepared; one without filling material and three sets filled with TiO_2 nanoparticles in contents of 0.1, 0.2 and 0.3 wt. %. Composites resin is manually blended with titanium dioxide nanoparticles. Then the mixture is packed into plastic tubes. The specimens are then polymerized from both sides for 10, 20, 40, 60 and 80 seconds using light emitting diode source. To determine the friction coefficient, all specimens are tested with reciprocating sliding apparatus at room temperature. The test conditions are; time = 1 minute, 60 stroke/minute and load = 6, 8, 10, 12 and 14 N. Results show that the friction coefficient is found to decrease with increasing curing time at all values of the normal load. The friction coefficient of the studied hybrid composite is decreased gradually by adding 0.1, 0.2 and 0.3 wt. % of titanium dioxide nanoparticles. Also, friction coefficient of the tested specimens is significantly affected by the normal load. Based on these results, it may be concluded that friction coefficient of the tested specimens is dependent on the curing times, TiO_2 nanoparticles content and normal load.

KEYWORDS
Curing times, dental nanocomposite, friction coefficient, titanium dioxide, nanoparticles, hybrid composite resin, normal load, reciprocating.

INTRODUCTION
The objective of the research in tribology is to decrease and remove losses that occur due to friction and wear at all levels, where rubbing, grinding, polishing, and cleaning of surfaces take place. Friction is the impedance to motion that happens whenever one solid body is in contact with another solid body [1]. Wear is defined as a consequence of the interaction between surfaces moving in contact, causing gradual remove of material [2]. Sometimes it is mistakenly assumed that interfaces with high friction show a high rate of wear. This is not generally true; both friction and wear have to be determined. There are cases when solid interfaces of polymers show relatively low friction but fairly high wear, while ceramic surfaces show moderate friction but very low wear [1].

Composite resins are increasingly used for restorative objectives because of good esthetic and the capability of establishing a bond to enamel and dentin. However, like all dental materials, composites have their own limitations, Such as the gap formation caused by polymerization contraction during setting, leading to marginal discoloration and leakage. In addition, they are subjected to higher wear rates than ceramics, and although some composites have wear rates similar to amalgam, many have higher wear rates. Refinements of mechanical properties of the composite materials have permitted its use in posterior teeth with greater reliability than was the case some years ago. These refinements included; development of smaller particle sizes of filler, better bonding systems, curing improvements and sealing systems [3]. The utilization of nanoparticles has become an important zone of survey in dentistry field. Titanium dioxide nanoparticles have been proposed for usage as reinforcing fillers to dental composite resin and epoxy. TiO_2 as an inorganic filler has many promising characteristics as it is non-toxic, biocompatible and chemically stable, [4]. It was concluded that the change of the friction coefficient depends on the size and volume fraction of the nano filling materials, [5].

Figure 1 display the main parameters affecting the friction. It is presumed that the friction force is proportional to the normal load; and experiments have shown this rule to be valid for some polymers at mild and severe contact pressure (PTFE, PMMA, PVC, PE, and PA), [6]. When the load increases the friction coefficient decreases but only at elastic contact. When plastic deformation starts, the friction coefficient is small but rises due to further load rise. The temperature of the contact has an important effect on the friction coefficient and the wear resistance. For polymers with higher glass transition temperature the ultimate value of the friction coefficient shows at higher sliding speed, [7].

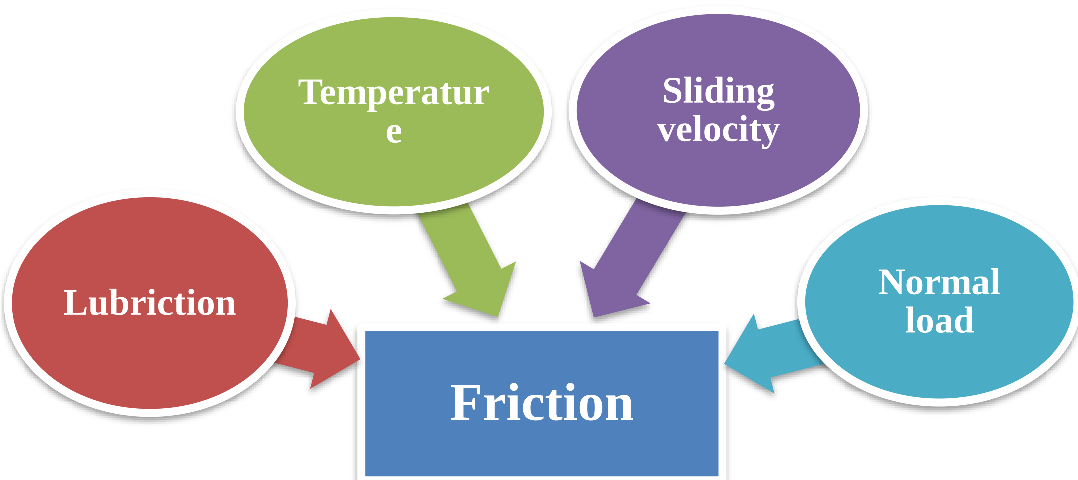

Fig. 1 Main factors affecting on the friction.

The sliding speed effects strongly on the friction coefficient. At low velocity the viscous impedance of polymer in the contact zone increases with increasing velocity. At high velocity the polymer in the contact zone explains elastic behavior; as a result, the friction force depends lightly on velocity or reduces with velocity increase, [6]. It was shown that the usage of lubricant into a polymer composite field lead to reduce the friction coefficient, [9].

Several studies have examined the effect of normal load on the coefficient of friction. Lin [10], revealed that there is a gradual reduction in the coefficient of friction of the polymer based nanocomposites over a wide range of applying loads. It was discovered that the friction coefficient depend on the normal load, as normal load increases, the value of friction coefficient increases, [11, 12]. On the other hand, friction coefficient reduces with the increase in normal load for glass fiber, PTFE and nylon, [13]. The effect of titanium dioxide nanoparticles on wear of short fiber reinforced epoxy under different loading conditions was examined, [14]. They observed that the addition of 5 vol. % of TiO_2 nanoparticles could importantly reduce the coefficient of friction of epoxy composites than padding only by conventional fillers.

This work is done to investigate the effect of curing times, TiO_2 nanoparticles and normal load on the friction coefficient of hybrid composite resin.

EXPERIMENTAL

The materials used in this work are hybrid composite resin of shade A1 and titanium dioxide nanoparticles (TiO_2 nanoparticles) with diameter of < 25 nm. Information about the materials used in the present work is shown in Tables 1 and 2.

Table 1. Specifics of Composite Resin.

Description	Classification	Manufacturer	Shade	Curing	Lot no.
Visible light cure, Resin-based dental restorative material	Hybrid composite	Prime-Dent, U.S.A.	A1	Light cure	YL08Q

Table 2. Specifics of TiO_2 Naoparticles.

Diameter	Density	Surface area
21 nm	4 g cm^{-3}	50 m^2 g^{-1}

PREPARATION OF TEST SPECIMENS

In this work, there are four experimental groups consisting of three hybrid composites resin containing TiO_2 nanoparticles in different content of 0.1, 0.2 and 0.3 wt % and one control group, containing no TiO_2 nanoparticles. The method of preparation of specimens is illustrated else well, [15]. Fifteen specimens were fabricated for each group

using gradually strong mode, flashing mode and strong mode. The shape and dimensions of sample are illustrated in Fig. 2.

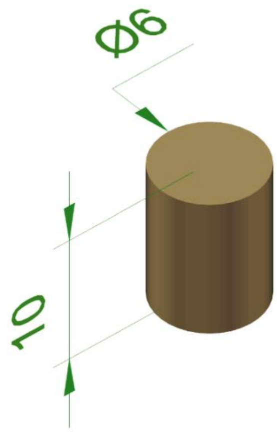

Fig. 2 Test specimens.

CURING OF SPECIMENS

The light source used in this work to cure specimens is blue light emitting diode (LED). Figure 3 displays the curing of the specimens by light emitting diode source. Elaborated information about the LED is shown in the Table 3. The light curing modes used in this research were as follows; gradually strong, flashing and strong mode.

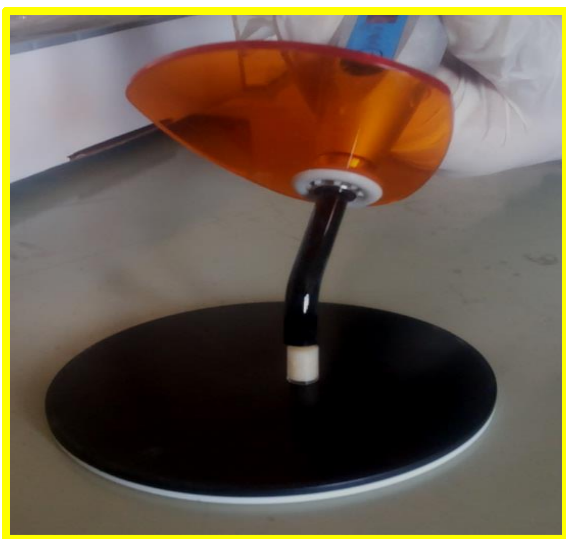

Fig. 3 Curing of the specimens by light emitting diode source (LED).

Table 3. Specifics of the Light Emitting Diode (LED)

Intensity (mW/cm^2)	Spectral emission (nm)	Solidification time and depth
1200 - 2000	420 - 480	5s, 3 mm

FRICTION TEST

To evaluate the friction coefficient of the specimens, cylindrical specimens (6 mm in diameter and 10 mm in length) of each condition are made in plastic tubes of 6 mm diameter and 10 mm height. Friction force is evaluated through subjecting the specimens to friction test at different normal loads against emery paper (1000 grit size) counterface using reciprocating sliding apparatus. For each normal load, the friction coefficient is determined using the relationship:

$$\mu = F / N \qquad [1]$$

where μ is the friction coefficient, F friction force and N normal load. The test conditions are; Velocity = 60 strokes/min., load = 6, 8, 10, 12 and 14 N and time = 1 min. Figure 4 shows the reciprocating sliding apparatus.

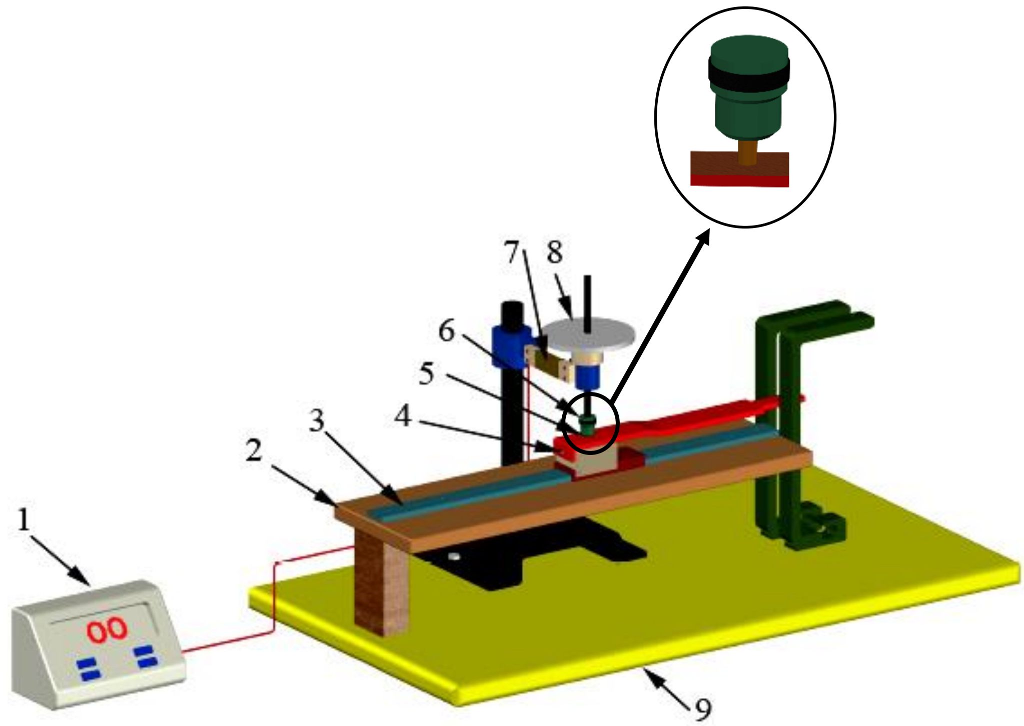

Fig. 4 The reciprocating sliding apparatus: (1) Friction force screen, (2) Plate, (3) Linear bearing, (4) Table, (5) Test sample, (6) Specimen jig, (7) Load cell, (8) Normal load, (9) Base plate.

RESULTS AND DISCUSSION

Friction coefficient μ versus curing time of the gradually strong mode, flashing mode and strong mode are shown in Figs. 5, 6 and 7, respectively for control group specimens. From Figs. 5, 6 and 7, it is clear that friction coefficient (μ) decreases with increasing curing time at all values of normal loads. The decrease in μ is related to the increase of the hardness, [15]. As seen in Fig. 5, the highest value of μ is 1.48 at 20 seconds curing time and 6 N normal load, while the lowest one is 0.757 at curing time 80 second and

normal load 14 N. Figs 5, 6 and 7 demonstrate that the curing time 80 seconds gives the minimum μ at all normal loads used. Friction coefficient appears to depend on the normal load, where the normal load increases, μ decreases. The reason for the decrease in μ is attributed to extra heat generated during sliding at loads higher than a critical value, [16]. The normal load 14 N has the lowest μ, while the normal load 6 N has the highest μ.

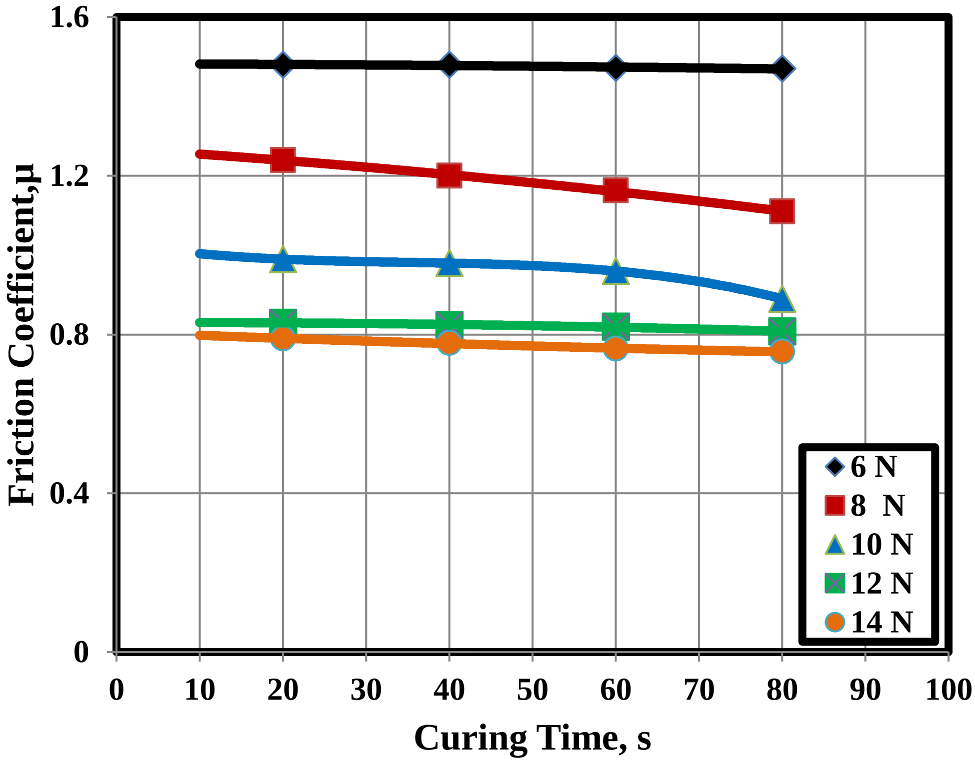

Fig. 5 Effect of curing time on friction coefficient for control group specimens in gradually strong mode.

The effect of TiO_2 nanoparticles on μ of the gradually strong, flashing and strong mode dental nanocomposites at different normal loads are presented in Figs. 8, 9 and 10, respectively at curing time 80 seconds. The obtained results as shown in Figs. 8, 9 and 10, revealed that μ is influenced by content of TiO_2 nanoparticles and normal loads. Friction coefficient displayed by the three modes decrease with the increase in the content of TiO_2 nanoparticles at all the values of normal load. The hybrid composite with no TiO_2 nanoparticles appeared to exhibit significantly higher μ compared to the hybrid composite containing 0.1, 0.2 and 0.3 wt. % TiO_2 nanoparticles. The hybrid composite containing 0.3 wt. % TiO_2 nanoparticles gives lowest μ. As indicated in Figs. 8, 9 and 10, μ decreases with increasing the normal load when TiO_2 content increases from 0 wt. % to 0.1 wt. % and it first increases and then decreases with increasing the normal load when TiO_2 content increases from 0.1 wt. % to 0.3 wt. %. The reason for the rise in μ is attributed to the increase in the contact area when the load is increased.

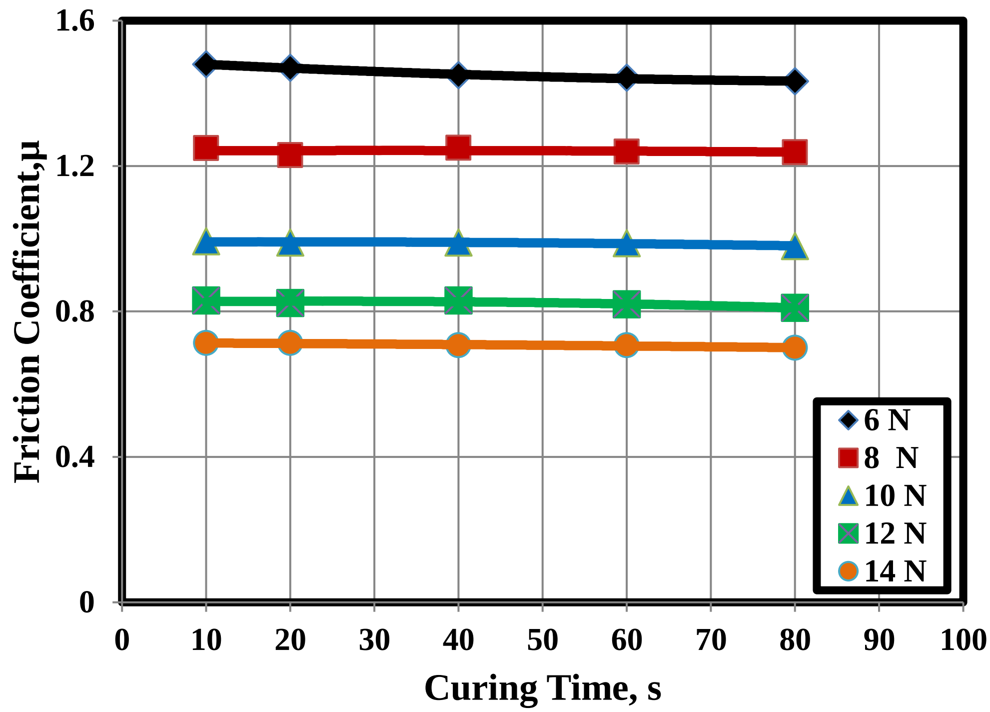

Fig. 6 Effect of curing time on friction coefficient for control group specimens in flashing mode.

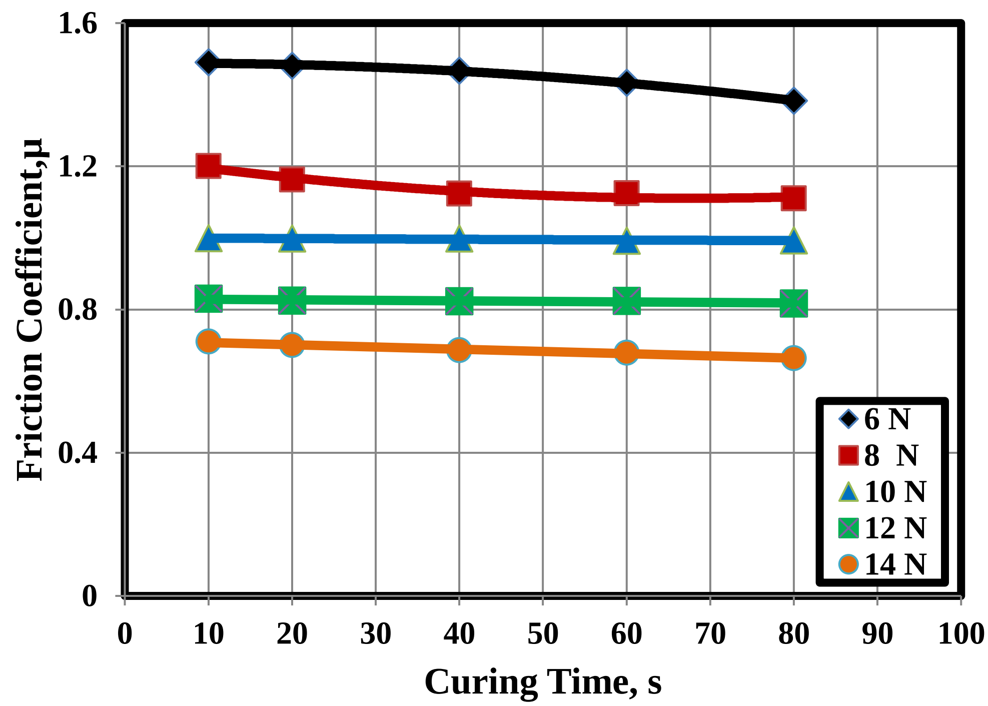

Fig. 7 Effect of curing time on friction coefficient for control group specimens in strong mode.

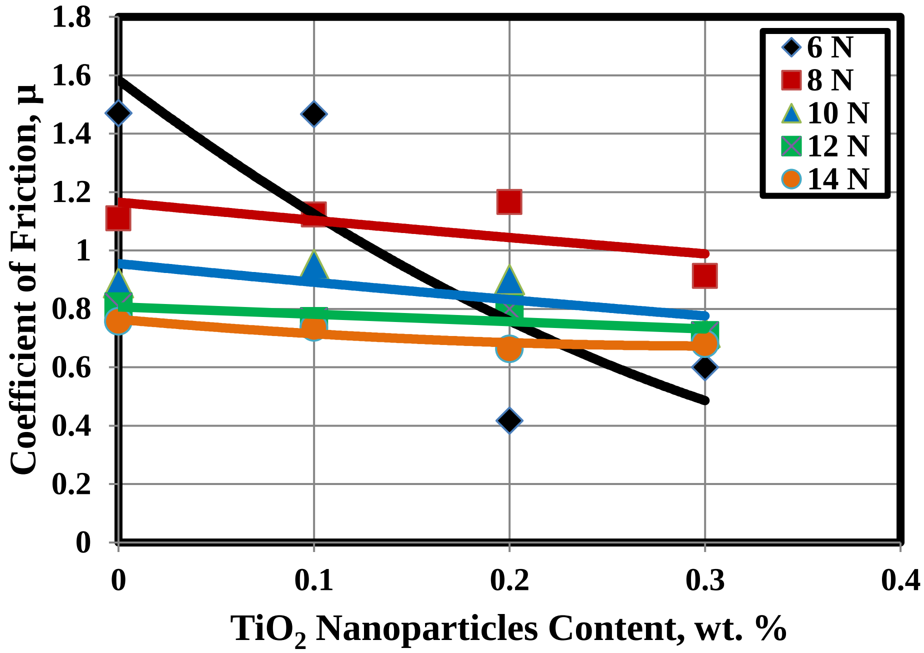

Fig. 8 Effect of TiO_2 nanoparticles content on friction coefficient for specimens of gradually strong mode at 80 seconds.

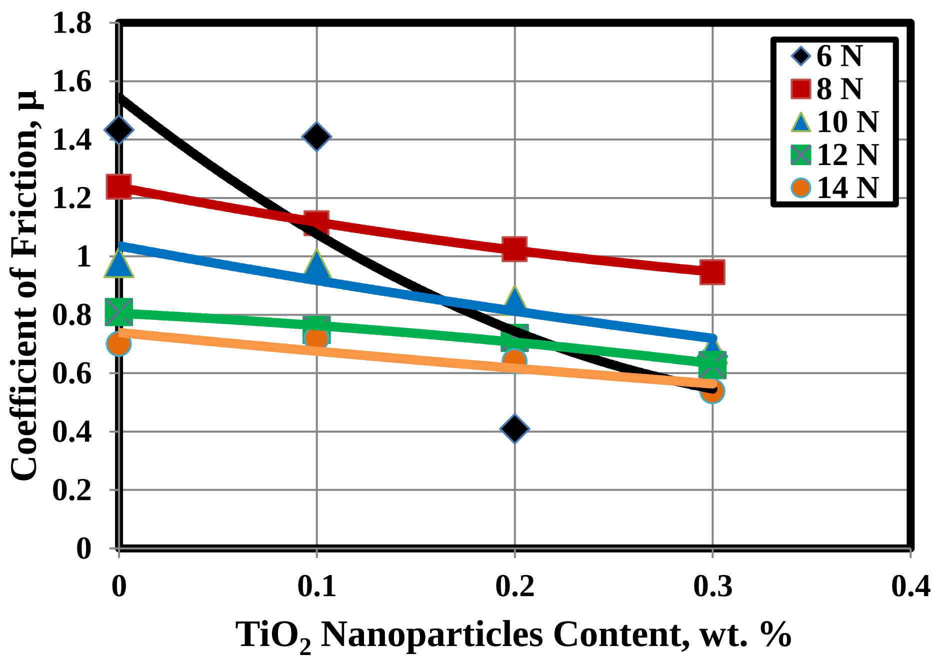

Fig. 9 Effect of TiO_2 nanoparticles content on friction coefficient for specimens of flashing mode at 80 second.

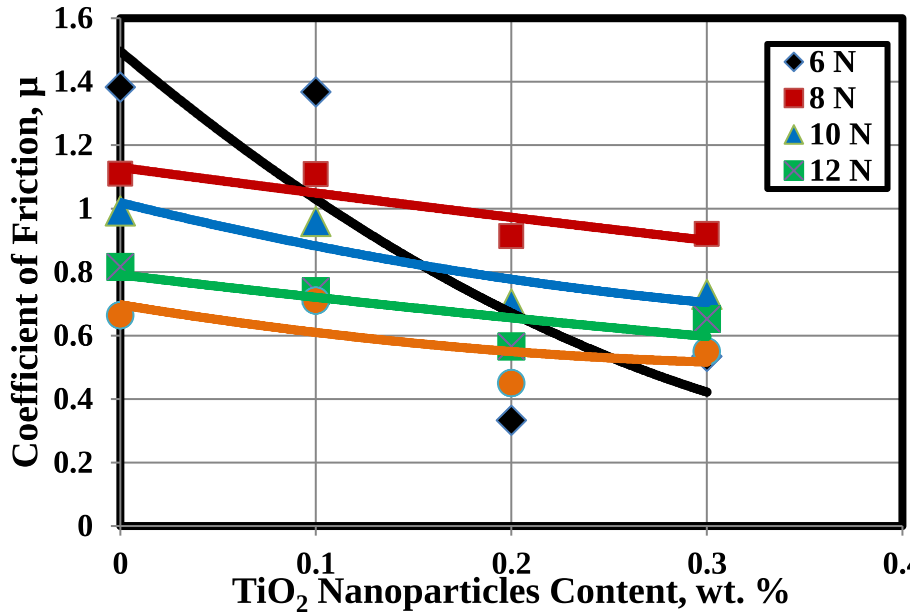

Fig. 10 Effect of TiO_2 nanoparticles content on friction coefficient for specimens of strong mode at 80 second.

The fall in the μ after the maximum is possibly due to extra heat which is generated during sliding at loads higher than a critical value, [16]. As it is evident in Figs. 8, 9 and 10, the normal load 6 N gives the minimum μ at higher content of TiO_2 nanoparticles, while the normal load 14 N gives the minimum μ at lower content of TiO_2 nanoparticles. Based on these results, it may be conclude that μ of tested specimens dependent on the curing times, content of TiO_2 nanoparticles and normal loads.

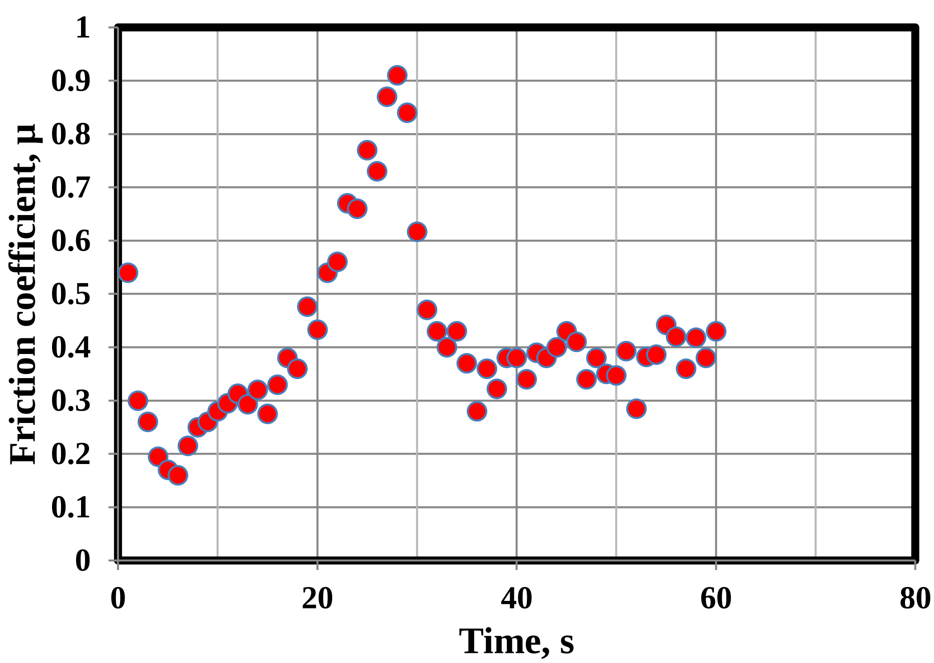

Fig. 11 Friction coefficient as a function of time for 40 second, flashing mode sample containing 0.3 wt. % TiO_2 nanoparticles at 6 N normal load.

Friction coefficient displayed by specimens cured at 40 second, flashing mode sample containing 0.3 wt. % TiO_2 nanoparticles, as a function of time, is shown in Fig. 11 at 6 N normal load. This Figure indicates that, the value of μ at the time of test starting is 0.54 and then decreases for few seconds then increases with increasing the time to 0.91 and after that it decreases with increasing the time to 0.32 and then it remains constant for the rest of the experimental time. From the shape of the coefficient of friction curve, it can be seen that hyper composite resin filled with 0.3 wt. % TiO_2 nanoparticles has steady friction. For this sample, the friction coefficient reaches a steady state after 40 second.

CONCLUSIONS

From the present study carried out on the hybrid composite resin and nanocomposite resin, the following conclusions can be drawn:

1. Friction coefficient decreases with increasing curing time.

2. By adding 0.1, 0.2 and 0.3 wt. % of titanium dioxide nanoparticles to the hybrid composite, μ of nanocomposite resin decreases.

3. Friction coefficient decreases with increasing normal load when TiO_2 nanoparticles percent increases from 0 to 0.1 wt. %.

4. Curing times, TiO_2 nanoparticles content and normal load have significant influence on μ results of hybrid composite resin.

REFERENCES

1. Witold B., Vera K., Domagoj V. and Jenna W., "Tribology of Polymers and Polymer-Based Composites", Journal of Materials Education, Vol. 32, No. (5 - 6), pp. 273 - 290, (2010).

2. Liqun C., Xinyi Z., Xu G., Shouliang Z., "An in Vitro Investigation of Wear Resistance and Hardness of Composite Resins, Int J Clin Exp Med, Vol. 6, No. (6), pp. 423 - 430, (2013).

3. Ibrahim M. Hamouda, Hagag Abd Elkader, "Evaluation the Mechanical Properties of Nanofilled Composite Resin Restorative Material, Journal of Biomaterials and Nanobiotechnology, Vol. 3, pp. 238 - 242, (2012).

4. Elsaka S. H., Hamouda I., Swain M., "Titanium Dioxide Nanoparticles Addition to a Conventional Glass-Ionomer Restorative: Influence on Physical and Antibacterial Properties", Journal of Dentistry, Vol. 39, pp. 589 - 598, (2011).

5. Ayman A. Aly, El-Shafei B. Zeidan, AbdAllah A. Alshennawy, Aly A. El-Masry, Wahid A. Wasel, "Friction and Wear of Polymer Composites Filled by Nano-Particles", World Journal of Nano Science and Engineering, Vol. 2, pp. 32 - 39, (2012).

6. Myshkin N.K., Pesetskii S.S. , Grigoriev A.Ya., "Polymer Tribology: Current State and Applications", Tribology in Industry, Vol. 37, No. (3), pp. 284 - 290, (2015).

7. RYMUZA Z., "Tribology of Polymers", Archives of Civil and Mechanical Engineering, Vol. VII, No. (4), pp. 177 - 184, (2007).

8. Tanaka K., "Friction and wear of semicrystalline polymers sliding against steel under water lubrication", Trans ASME J Lubricat Technol, Vol. 102, No. (4), pp. 526 - 533. (1980).

9. Evans D. C., "Polymer–fluid interaction in relation to wear. In: Proceedings of the third Leeds–Lyon symposium on tribology, the wear of non-metallic materials", Mechanical Engineering Publication Ltd., pp. 47 - 55. (1978).
10. Lin J. C., "Compression and Wear Behavior of Composites Filled with Various Nanoparticles", Composites, Part B, Vol. 38, pp.79 - 85, (2007).
11. Unal H. and Mimaroglu, A., "Friction and wear behavior of unfilled engineering Thermoplastics", Material Design, Vol. 24, pp. 183 - 187. (2003).
12. Suresha, B., Chandramohan, G., Prakash, J.N., Balusamy, V., and Sankaranarayanasamy, K., "The role of fillers on friction and slide wear characteristics in glass-epoxy composite systems", Journal of Minerals & Materials Characterization & Engineering, Vol. 5, No. (1), pp. 87 - 101, (2006).
13. Nuruzzaman, D.M., Chowdhury, M.A., and Rahaman, M.L. "Effect of Duration of Rubbing and Normal Load on Friction Coefficient for Polymer and Composite Materials", Industrial Lubrication and Tribology, Vol. 63, pp. 320 - 326. (2011).
14. Chang L., Zhang Z., Breidt C. and Friedrich K., "Tribological Properties of Epoxy Nanocomposites: I. Enhancement of the Wear Resistance by Nano-TiO2 Particles," Wear, Vol. 258, No. 1 - 4, pp. 141 - 148, (2004).
15. Meshref A. A., Mazen A. A., El-Giushi M. A. and Ali W. Y., "Effect of Curing Process of Dental Nanocomposite Resin on Shore Hardness, EGTRIB Journal, Vol. 13, No. (2), pp. 25 - 37, (2016).
16. Sarkar A. D., "Friction and Wear", Acadamic Press, London, P. 247, (1980).