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HARDNESS AND FRICTIONAL BEHAVIOUR OF DENTAL HYBRID COMPOSITE RESIN FILLED BY SILICON CARBIDE NANOFIBERS

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ABSTRACT
The objectives of the present investigation is to determine the effect of light curing time on the hardness and friction coefficient of composite resin filled with (SiC NFs). The materials used are hybrid composite resin and SiC NFs. Four groups of composite resin specimens are prepared; one as received and three groups reinforced by SiC NFs in concentrations of 0.1, 0.2 and 0.3 wt. %. SiC NFs are manually mixed with hybrid composites resin. The resulting paste is packed into plastic bars. The specimens are then cured from both sides for 40, 60 and 99 seconds using a visible light curing unit. Surface hardness is measured using Shore D durometer test. The coefficient of friction is determined using two-body abrasion test.

It was found that high curing times gave higher hardness values and moderate friction coefficient compared to low curing times. The minimum content of SiC NFs (0.1 wt. %) improved the hardness and frictional behavior. Based on that, it may be concluded that hardness and friction coefficient are significantly affected by curing times and SiC NFs concentrations.

KEYWORDS
Silicon carbide nanofibers, hybrid composite resin, curing times, friction coefficient, shore hardness.

INTRODUCTION
Dental restorative materials are designed to afford a tooth back the form and function that it has lost through injury or disease. Dental restorative materials should clearly be non-toxic, non-irritant, non-corrosive and non-degradable. It is also particularly significant that they are easy to use. Although filling the cavity and restoring the tooth is significant, a major goal in restorative dentistry should be the preventing of further caries, [1]. The ideal restorative materials should be identical to the structure of natural tooth, both in appearance, and strength, [2]. The two major categories of dental restorative materials are, amalgam and composites resin, [3]. Dental composites resin

are tooth-colored materials that consist of four main components: organic polymer matrix, inorganic filler particles, coupling agent, and the initiator accelerator system. Although significant improvements have been made in the properties of dental composites resin over the years, no composite materials are able to meet both the functional needs of posterior class I and class II restoration and the superior esthetics required for anterior restorations, [4]. The improvements in the durability of dental composites resin depend on a thorough understanding of the behavior of wear of the resin matrix, [5]. Understanding of dental friction and wear behavior would help the clinical management of tooth wear, which involves the alteration of missing tooth tissue with dental materials, together with an attempt to decrease the causal factors and improve new dental materials. Therefore, tribology of dental materials has improved and is paid rising attention by various researchers, [6]. Figure 1 indicates the main parameters affecting the friction and wear.

Nanocomposite materials have been introduced to serve functional needs of posterior class I, class II restoration and the superior esthetics desired for anterior restorations through the application of nanotechnology, [4]. Nanoparticles have been introduced as materials with good potential to be extensively used in medical and biological applications. Nanoparticles are constituted of various tens or hundreds of atoms or molecules and can have a variety of sizes and morphologies. Nanoparticles are defined as man-made materials containing structures with at least one dimension being less than 100 nm and have characteristics unique from their bulk equivalent. As a result of their small size, nanoparticles may display other advantages to the biomedical field through improved biocompatibility, [5 - 11]. Metal oxides are a large and significant class of chemical compounds in which oxygen was combined with metals. Metal oxides including titanium dioxide, zinc oxide, iron oxide, aluminum oxide, zirconium dioxide and silicon dioxide and other oxides. Modern studies have showed that specially formulated metal oxide nanoparticles have good antibacterial activity. Major applications of metal oxides nanoparticles are electronics, pharmacy/medicine, cosmetics as well as chemistry and catalysis, [8, 10, 12].

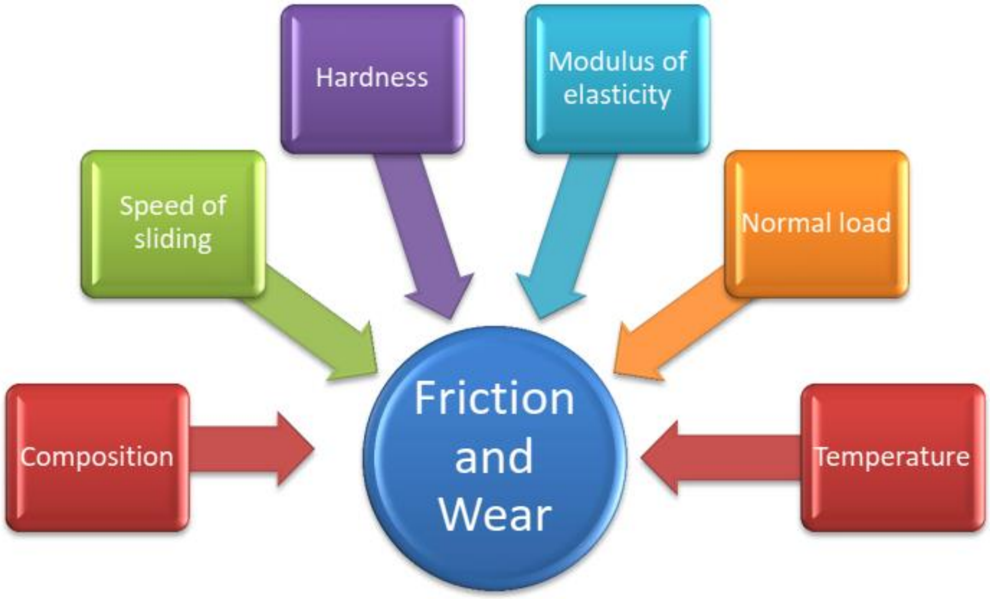

Fig. 1 Main factors affecting the friction and wear behavior, [7].

Recently, nanofill/nanohybrid composites have been found to show acceptable clinical performance in restorations of occlusal cavities of posterior teeth. Moreover, the application of alumina-whisker-reinforced composites in dental applications might be promising for growing hardness and fracture toughness compared with other materials, [13].

Various studies have examined the influence of oxides nanoparticles on the tribological properties of dental composites resin. Meshref et al., [14] study the influence of titanium dioxide nanoparticles on the friction coefficient of dental hybrid composite resin. Results showed that 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. Ibrahim M Hamouda et al., [15] evaluated the wear resistance, of a nanofilled composite resin restorative material in comparison with a conventional hybrid composite resin. Results showed that the nanofilled composite resin exhibited higher wear resistance than that of hybrid composite resin materials.

The goal of the present work is to study the effect of SiC Nanofibers content on the friction coefficient and hardness of the dental composites resin.

EXPERIMENTAL SETUP

The Present section presents the experimental work performed to achieve the objectives of the study. The section outline includes the materials used, preparation of specimens, curing of specimens, hardness test and wear test.

Materials

Materials used in this investigation are hybrid composite resin of shade A3 and silicon carbide nanofibers (SiC NFs) of diameter < 25 nm. The details of the materials used in the study are shown in Figs. 2 and 3 and in Tables 1 and 2.

Fig. 2 hybrid composite resin.

Fig. 3 Silicon carbide nanofibers (SiC NFs).

Table 1: Details of Hybrid Composite Resin.

Description	Classification	Manufacturer	Shade	Curing	Lot no.
Visible light cure, Resin-based dental restorative material	Hybrid composite	Prime-Dent, U.S.A.	A3	Visible Light cure	PM8117

Table 2: Details of SiC Nanofibers.

Diameter	Density	Surface area
< 25 nm	$3.22\ g\ cm^{-3}$	$47.5\ m^2\ g^{-1}$

Test Specimens Preparation

The test specimens were prepared in four groups of hybrid composite resin; three groups containing SiC nanofibers in different concentrations of 0.1, 0.2 and 0.3 wt. %, and one in as-received condition, contained no SiC nanofibers. SiC nanofibers were weighed using a digital balance of accuracy of 0.0001 g and added to the hybrid composite resin. SiC nanofibers and the hybrid composite resin were hand-mixed on a mixing paper. Before curing, a plastic bars 6 mm diameter and 10 mm length are used to pack the resulting paste into it. A visible light curing unit (LED) is used to cure the specimens from both sides for different times 40, 60 and 99 seconds. The cured specimens were ejected from the bars and ground with emery paper (1000 grain size) and then polished. Figure 4 shows preparation methodology of specimens.

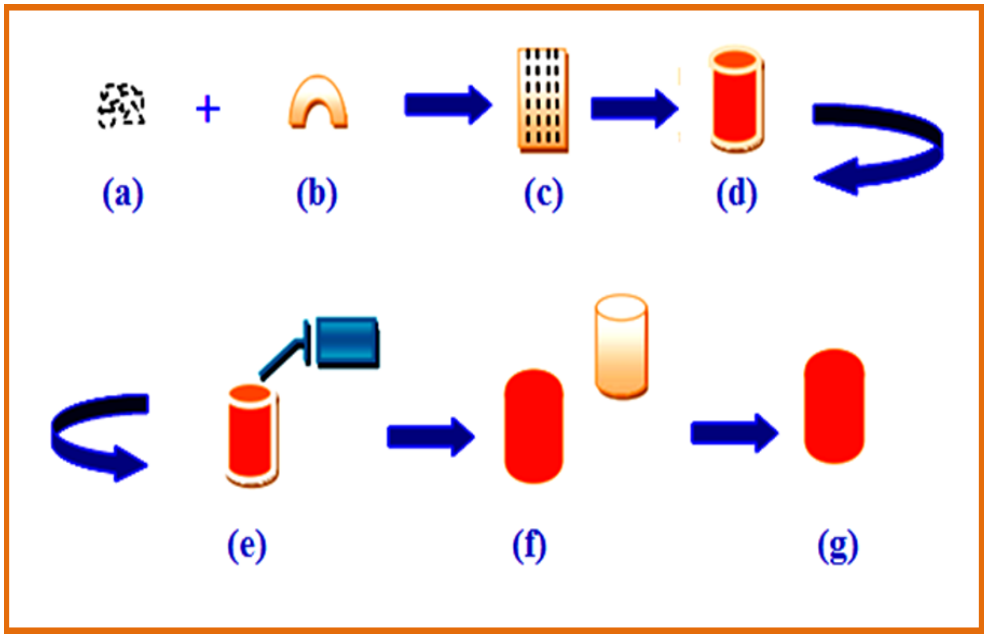

Fig. 4 Method of the preparation of specimens (a) SiC nanofibers (b) composite resin (c) mixing (d) packing (e) curing (f) removing (g) grinding and final shape of specimen.

Curing of Specimens

A blue light emitting diode (LED) Light source is used in this investigation to cure composites is. Figure 5 shows the light emitting diode source and Table 3 shows the details of the light source.

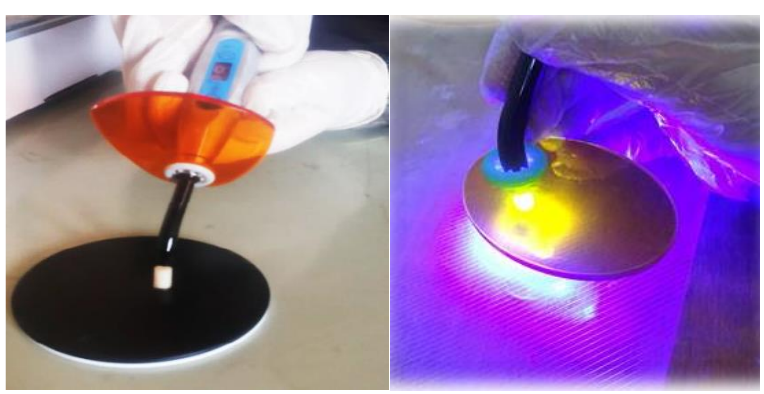

Fig. 5 light cure.

Table 3: Details of the Light Emitting Diode (LED).

Intensity (mW/cm2)	Spectral emission (nm)	Solidify time and depth
1200 - 2000	420 - 480	5s/3 mm

Shore D Hardness Test

To measure the surface hardness of the specimens, cylindrical specimens (diameter = 6 mm, height = 10 mm) were prepared for each group. Shore D durometer instrument shown in Fig. 2.7 was used with dial value (1-100 degree), pointer journey (0-2.5 mm), and the stress at the end of pointer range from 0 to 44.5 N. Hardness was measured on both sides of the specimens (top and bottom). Four measurements per specimen were carried out, two on the top and two on the bottom side of each specimen. The average of the four measurements was taken as the hardness of the specimen.

Friction Test

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

$$\mu s = Fs / FN$$

Where µs is the coefficient of friction, Fs friction force and FN normal load. The test conditions were; sliding speed = 173 cycle/ minute, load = 6, 8, 10, 12 and 14 N, time = 1 minute. Fig. 6 shows the two-body abrasion, reciprocating sliding apparatus.

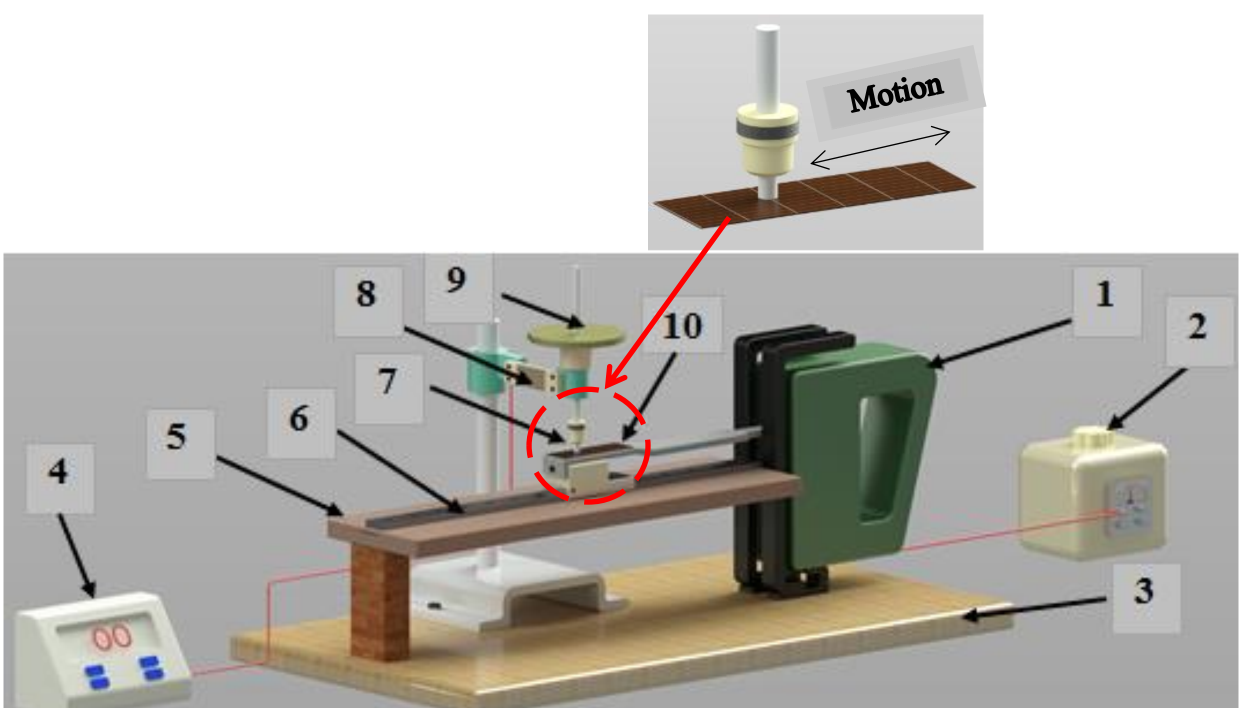

Fig. 6 reciprocating test rig.
1. Motor, 2. Voltage regulator, 3. Base, 4. Friction force screen, 5. Plate, 6. Linear Bearing, 7. Sample, 8. Load cell, 9. Normal Load, 10. Emery Paper

The friction test was done under dry and wet conditions for 4 minutes at 6, 8, 10, 12 and 14 N loads. The lubricating liquid used in wet condition is called Artificial saliva. The artificial saliva composition is illustrated in Table 4.

Table 4: Artificial saliva composition

Compound	Na_2HPO_4	$NaHCO_3$	$CaCl_2$	H_2O	HCL-1M
Concentration	0.4 g	1.7 g	0.15 g	800 ml	2.5 ml

RESULTS AND DISCUSSION

Influence of concentration of SiC NFs on the coefficient of friction

Dry Conditions.

Figures 7, 8 and 9 show the effect of concentration of SiC nanofibers on the coefficient of friction of specimens cured at 40, 60 and 99 seconds respectively at different loads and dry condition. The results as shown in the below figures revealed that the friction coefficient μ is influenced by both weight percent of SiC NFs and normal loads. The coefficient of friction μ decreased gradually with the increase of the wt. % of SiC NFs at all normal loads, so that the value of friction coefficient is dependent on SiC NFs contents. The hybrid composites with no SiC NFs appears to exhibit higher coefficient of friction compared to the hybrid composites containing 0.1, 0.2 and 0.3 wt. % SiC NFs, where μ decreases gradually down to minimum at 0.3 wt. % SiC NFs. The hybrid composites containing 0.3 wt. % SiC NFs gave the minimum coefficient of friction at the value of (6N) normal load and gave the maximum coefficient of friction at the value of (14N) normal load . In other words it can be said that the coefficient of friction increased with increasing the normal load, whereas the normal load increases the contact area increase so the more adhesion of asperities so the coefficient of friction will increase. The decrease in μ may be explained on the basis that extra heat generated during sliding with increasing normal loads. If the temperature is high enough, a layer of low shear strength material may be expected to form at the interface which provided low values of friction coefficient.

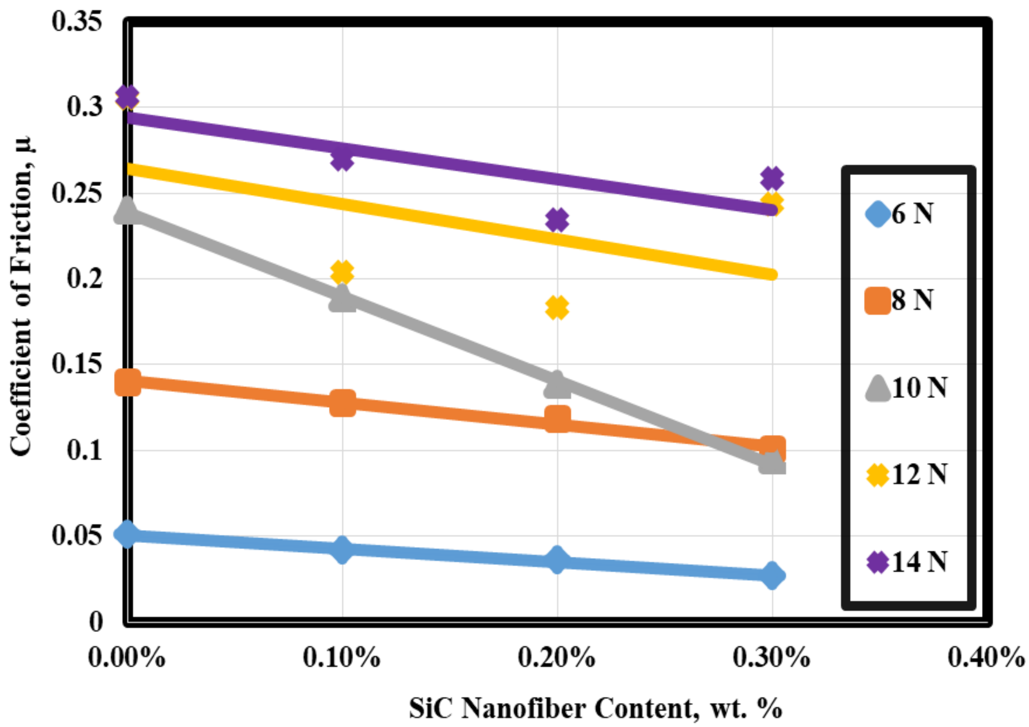

Fig. 7 Effect of concentration of SiC nanofibers on the coefficient of friction of specimens cured at 40 seconds at different loads and dry condition.

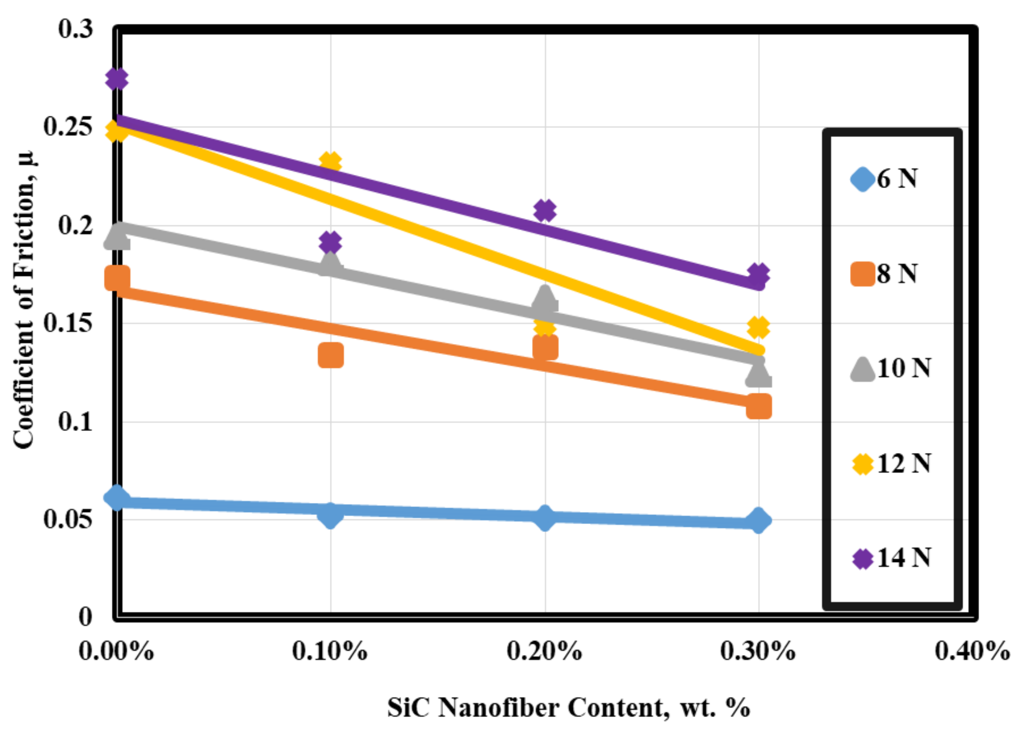

Fig. 8 Effect of concentration of SiC nanofibers on the coefficient of friction of specimens cured at 60 seconds at different loads and dry condition.

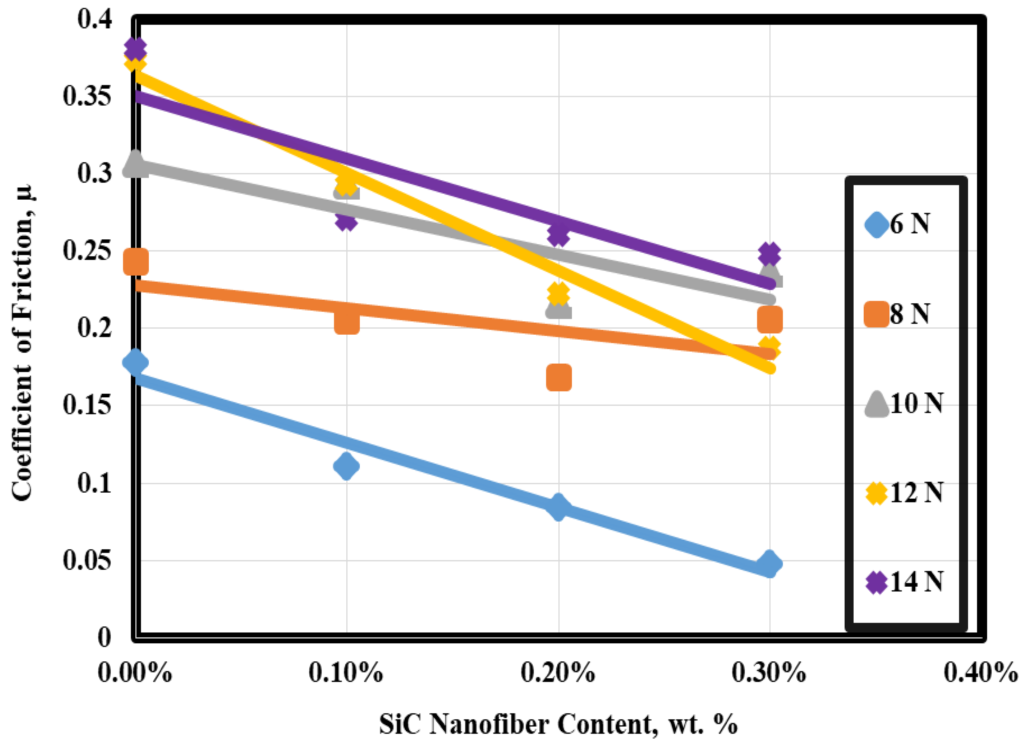

Fig. 9 Effect of concentration of SiC nanofibers on the coefficient of friction of specimens cured at 60 seconds at different loads and dry condition.

Wet Conditions

Figures 10, 11 and 12 show the effect of concentration of SiC nanofibers on the coefficient of friction of specimens cured at 40, 60 and 99 seconds respectively at different loads and wet condition. The figures below also investigated that the friction coefficient µ is influenced by both weight percent of SiC NFs and normal loads. It can be also noticed that the coefficient of friction µ decreased gradually with the increase of the wt. % of SiC NFs at all normal loads, so that the value of friction coefficient is dependent on SiC NFs contents. The hybrid composites with no SiC NFs appears to exhibit higher coefficient of friction compared to the hybrid composites containing 0.1, 0.2 and 0.3 wt. % SiC NFs, where µ decreases gradually down to minimum at 0.3 wt. % SiC NFs. The hybrid composites containing 0.3 wt. % SiC NFs gave the minimum coefficient of friction at the value of (6N) normal load and gave the maximum coefficient of friction at the value of (14N) normal load . In other words it can be said that the coefficient of friction

increased with increasing the normal load, whereas the normal load increases the contact area increase so the more adhesion of asperities so the coefficient of friction will increase. The decrease in μ may be explained on the basis that extra heat generated during sliding with increasing normal loads. If the temperature is high enough, a layer of low shear strength material may be expected to form at the interface which provided low values of friction coefficient. It can be shown that the values of friction coefficient of the specimens cured in the wet condition are lower than the values in dry conditions, where the used artificial saliva works as a lubricant and so it led to decrease in friction coefficient.

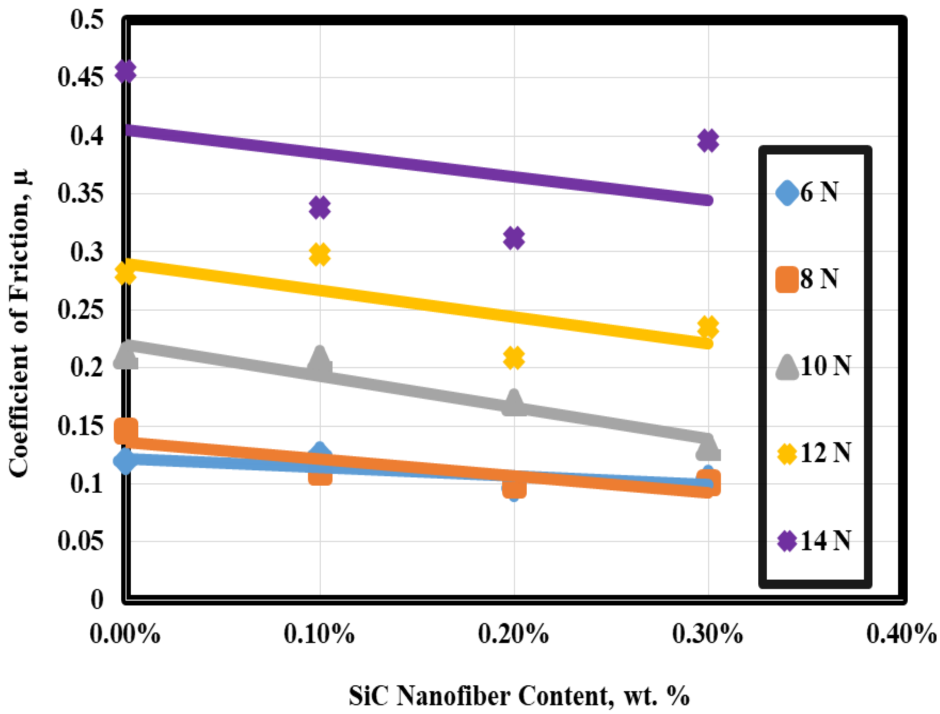

Fig. 10 Effect of concentration of SiC nanofibers on the coefficient of friction of specimens cured at 40 seconds at different loads and wet condition.

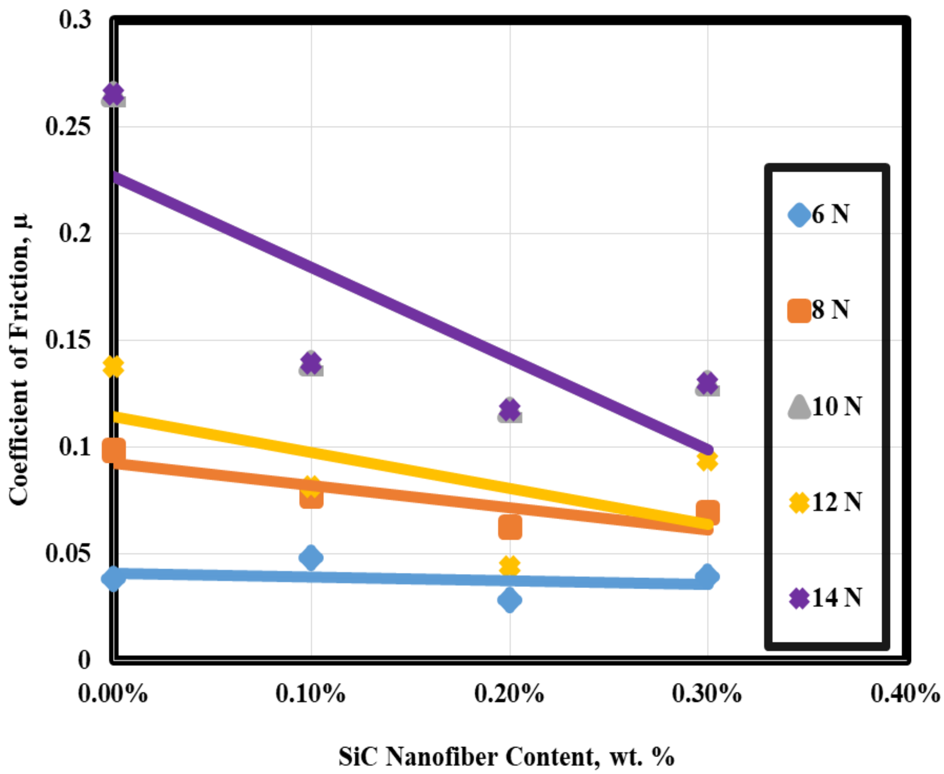

Fig. 11 Effect of concentration of SiC nanofibers on the coefficient of friction of specimens cured at 60 seconds at different loads and wet condition.

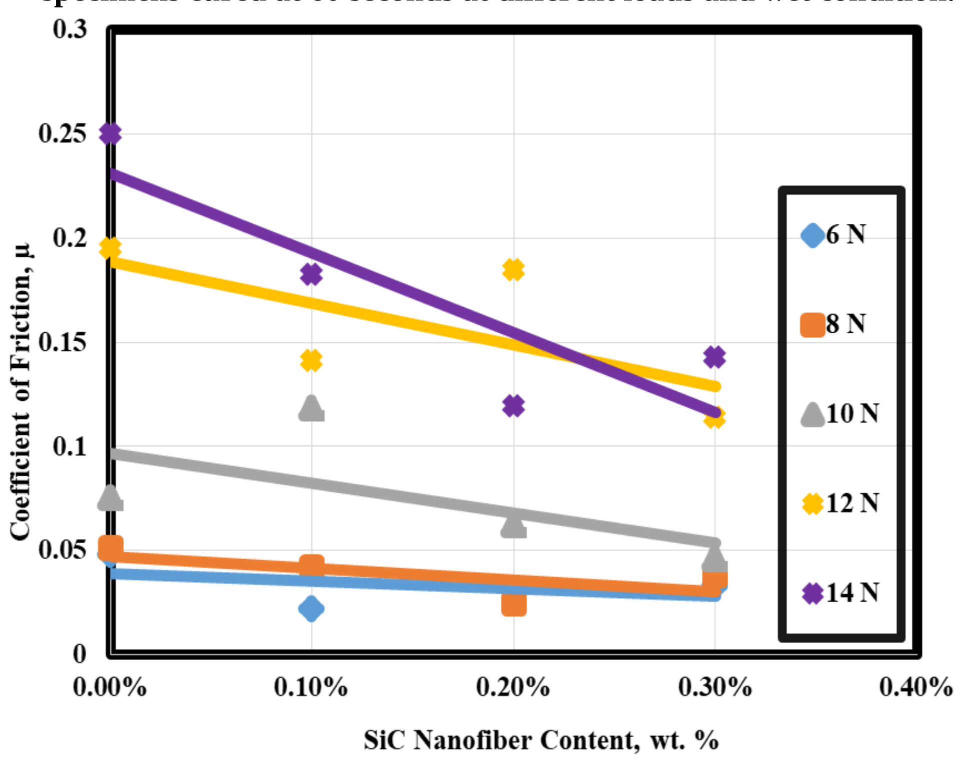

Fig. 12 Effect of concentration of SiC nanofibers on the coefficient of friction of specimens cured at 99 seconds at different loads and wet condition.

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Influence of concentration of SiC NFs on the hardness behavior

Shore hardness of hybrid composites resin and nanocomposites resin at 40, 60 and 99 seconds curing time are plotted as a function of the concentration of SiC nanofibers (Figure 13). It is clear that Shore hardness of the tested specimens increased from 0.0 wt. % SiC NFs to 0.1 wt. % SiC NFs, then decreased gradually at 0.2 and 0.3 wt. % SiC NFs. Generally the hybrid composites containing 0.1 wt. % SiC NFs theoretically exhibits the higher Shore hardness followed by the hybrid composites containing 0.2 wt. % SiC NFs, then the hybrid composites containing 0.3 wt. % SiC NFs and lastly the hybrid composites containing 0 wt. % SiC NFs for all specimens cured at 40,60 and 99 seconds respectively. In other words it can be said that the concentration of SiC nanofibers and curing time showed pronounced effects on Shore hardness, where the specimens containing 0.1 wt. % SiC NFs and cured at 99 seconds gave the highest hardness followed by specimens cured at 60 and 40 seconds respectively and containing the same content of SiC nanofibers. The increase of hardness with the increase of curing time may be due to the increasing of degree of conversion, where the higher the degree of conversion is, the better the mechanical properties (strength and wear resistance) of the hybrid composite resin. The reason for the increase in the Shore hardness at 0.1 wt. % of SiC NFs may be attributed to higher contact surface of nano fillers with the organic matrix, which leads to improved material strength and therefore a higher Shore hardness.

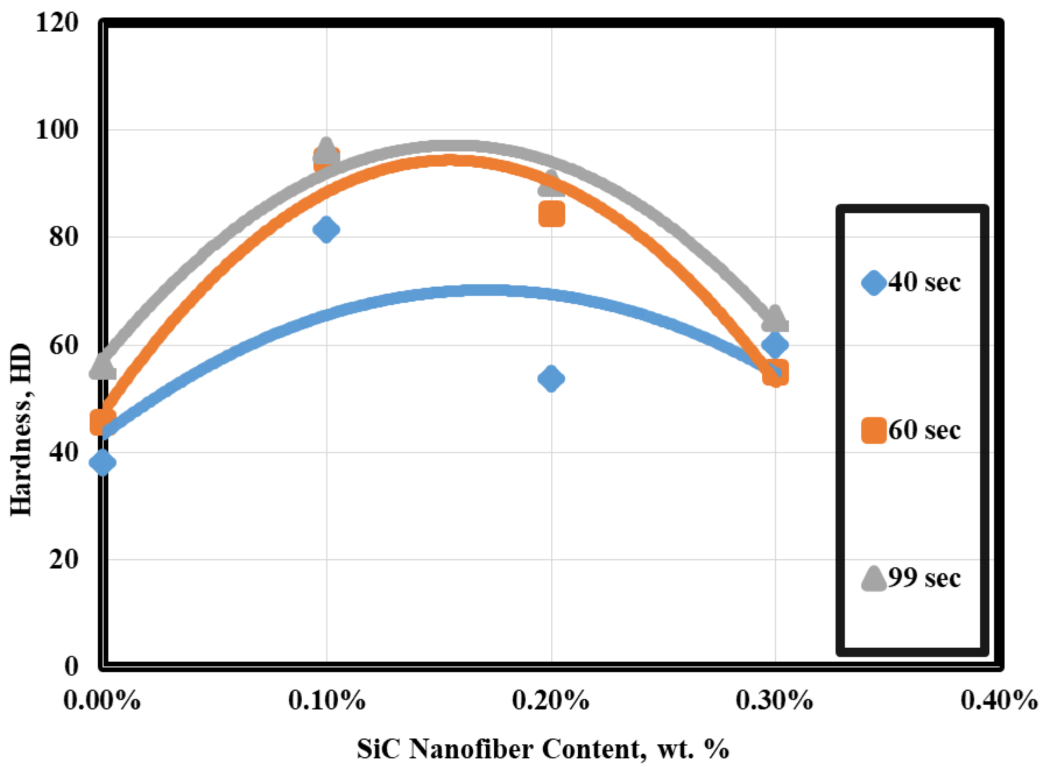

Fig. 13 Effect of concentration of SiC nanofibers on the hardness behavior of specimens cured at 40, 60 and 99 seconds.

CONCLUSIONS

The results showed that, the hardness and frictional behaviour of the hybrid composite dental nanocomposite resin depended on the curing times and concentrations of SiC NFs. From the experimental work, the following points can be concluded:

1. **Curing time of 99 seconds gives hybrid composite resin with higher hardness values and moderate friction coefficient.**
2. **The hybrid composite containing 0.1 wt. % SiC NFs and cured at 99 seconds appears to exhibit significantly the highest surface hardness, so it is recommended.**
3. **The coefficient of friction μ decreased with the increase in the wt. % of SiC NFs at all normal loads and increased with increasing the normal load.**
4. **The hardness for all specimens increased up to 0.1 wt. % SiC NFs , then decreased .**

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