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WEAR BEHAVIOUR OF DENTAL RESIN REINFORCED BY SILICON CARBIDE NANOFIBERS

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ABSTRACT
The present investigation studies the wear of dental resin filled by silicon carbide nanofibers (SiC NFs) concentrations. The materials used are dental resin and SiC NFs. Four groups of the 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 the dental resin. The specimens are then light cured from both sides for 40, 60 and 99 seconds using a visible light curing unit. It was found that high curing times give high wear resistance compared to low curing times. Wear resistance displayed by all the tested specimens increased up to 0.1 wt. % SiC NFs , then decreased with increasing SiC NFs contents. Besides, composite containing 0.3 wt. % SiC NFs gives the lowest wear resistance. Based on the results, it can be noticed that wear resistance are considerably affected by curing times and SiC NFs concentrations.

KEYWORDS
Silicon carbide nanofibers, dental resin, wear, curing time.

INTRODUCTION
The science of tribology studies the mechanisms of wear, friction and lubrication of reacting surfaces that are in relative movement. Generally, in the mouth, the biomechanical functions of oral can result in some motion of the tribological of restorations, teeth and implants. For example, pending the food chewing, the teeth both with any restorations have to shift in contact with each other and thereafter friction and wear occur in general with the lubrication of saliva or food slurry, [1]. Polymers are one of the well-accepted materials that are used for a wide variety of applications, so polymers are studied in the fields of engineering, chemistry, physics, and biomaterials science, [2 - 5].

The role of the investigation in tribology is to reduce and eliminate losses caused by friction and wear at all levels, wherever grinding, rubbing, polishing, and cleaning of surfaces happen, [6]. Wear resistance is so important to dental composites resin, especially when being utilized in regions with heavily loaded. Rates of failure are higher

for larger restorations, and may still be a significant method of failure for patients with clenching customs and bruxism. Investigation of the behavior of friction and wear is of pivotal significant to the development of dental material, [7]. One of the most utilized indirect procedures to determine the curing degree of the dental composites resin is the test of hardness, [8]. Number of hardness gives beneficial information on the curing depth when such measurements are carrying out on the top surface and bottom surface of the cured specimens. It can also give an allusion of the abrasion resistance and material polishability, [9 - 10].

Recently, fibrous materials have generated alertness in dental composites resin. Whiskers or glass fibers are proved to have better load transfer capability compared to special fillers due to the influences of fiber pullout and fiber bridging, who gave extra toughening mechanisms, [11].

For improvement of the mechanical properties of dental composites resin such as hardness, fracture toughness and compressive strength, previously papers have focused on the evolution of methods of curing and pretreatment of resin monomers and inorganic fillers, [12 - 13]. Filler modification, in terms of concentration of filler loading, size, type, surface treatment attracted the wide majority of interest between researchers, [14]. The type and percent of inorganic fillers have the great effect on the mechanical behavior of composites, [9]. Nanofibers and nanotubes have been used to strengthen dental composites in the academic and industry field, [15].

The usage of nanotechnology on the dentistry field is creating main changes with respect to advancement of health, diagnosis, and proper employ of natural resources. The utmost influence of nanotechnology on restorative dentistry is by contributing to the improvement of previously established clinical RBC systems with the help of nanomaterials such as nanofibers, nanotubes, quantum dots, , nanospheres, dendrimers, nanorods, nanoparticles, [16]. Nanoparticles and nanofibers are often employed as reinforcement for other material classes such as polymers, ceramics or metals to yield nanocomposites with special properties, [17].

Several studies have examined the effect of nanomaterials on the tribological properties of dental composites resin. Chang et al., [18], investigated the influence of titanium dioxide nanoparticles on epoxy reinforced with a short fiber under conditions of different loading on the tribological properties. The results showed that, the friction coefficient and the rate of wear reduced by the addition of 5.0 vol. % of TiO_2 nanoparticles. Manhart et al., [19], studied the effect of filler loading on the rate of wear of the composites resin. They found that, wear resistance of the composites resin significantly improved with increased filler loading. Meshref et al. [20] studied the effect of SiO_2 nanoparticles on Shore hardness number and wear resistance of the hybrid composite resin. The results showed that, the hybrid composite resin containing 0.2 wt. % silicon dioxide NPs exhibited the highest hardness, while the hybrid composite resin containing 0.1 wt. % SiO_2 nanoparticles had the highest resistance to wear. Ameer et al., [21 - 23] investigated the effect of nanofibres on the friction and wear of polymeric

composites. It can be noticed that the hardness, friction coefficient and wear resistance of polymeric composites affected by concentration of nanofillers and normal load.

The present investigation studies the effect of SiC Nanofibers content on the hardness, friction coefficient and wear behavior 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) with diameter < 25 nm. The details of the materials used in the study are shown in Figures 1 and 2 and in Tables 1 and 2.

Fig. 1 hybrid composite resin

Fig. 2 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 without 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 of 6 mm diameter and 10 mm length were 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 3 shows preparation methodology of specimens. Figure 4 shows specimen dimensions.

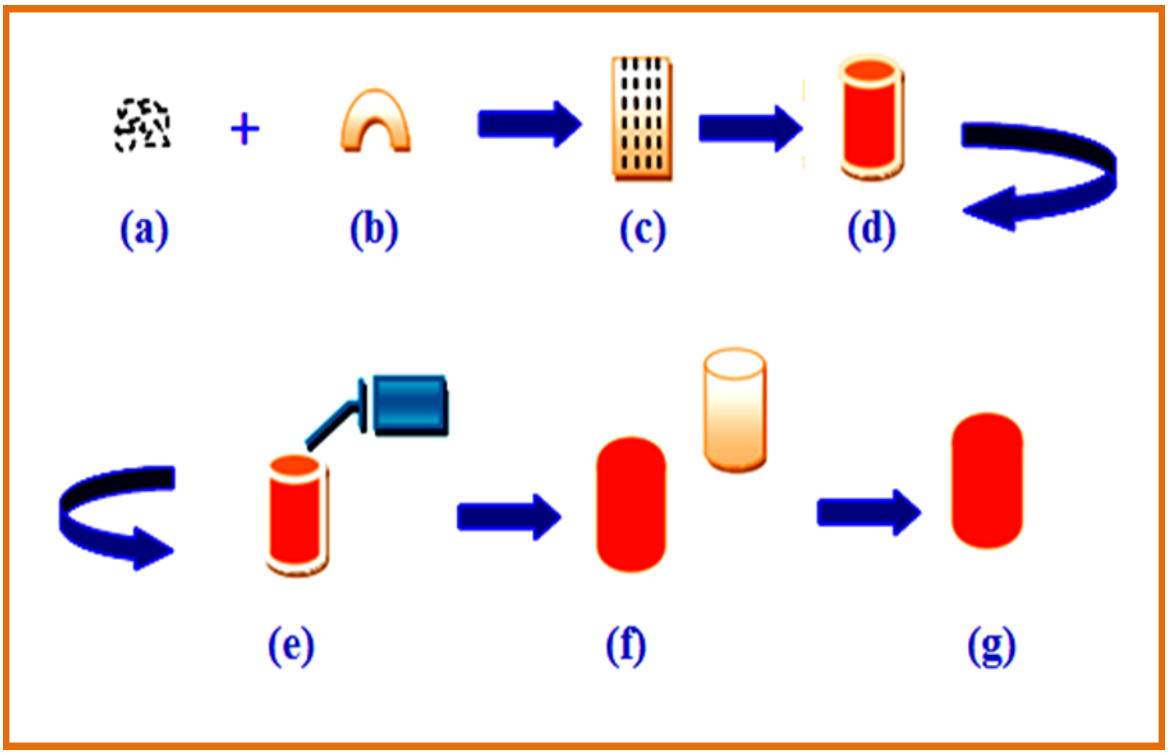

Fig. 3 Method of the preparation of specimens (a) SiC nanofibers (b) composite resin (c) mixing (d) packing (e) curing (f) removing (g) grinding and final shape of specimen.

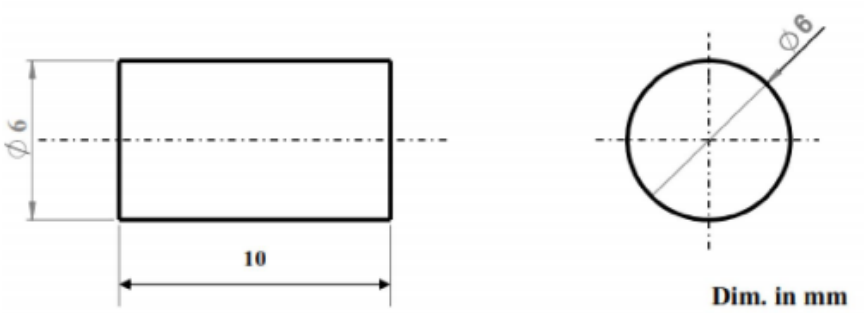

Fig. 4 Specimen dimensions

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.

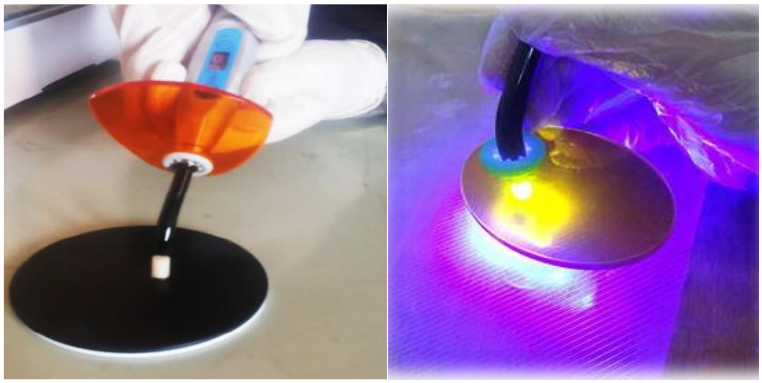

Fig. 5 light cure

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

Wear Test

The wear resistance of the test specimens with 6 mm diameter and 10 mm length has been examined. Each specimen was held in the test specimen holder of the test rig and examined under different normal loads of 6, 8, 10, 12 and 14 N against emery paper (1000 grain size) counter face to detect the wear of the specimens. The emery paper was adhered to the table of linear bearing. The table moved reciprocally at speed of 190 cycle/ minute. Each specimen was abraded for a running distance of six meter against fresh emery paper. The specimens were weighted before and after wear test using digital balance of ± 0.0001g accuracy, then wear was explained by the weight loss. Figure 6 shows two-body abrasion, reciprocating sliding apparatus.

The wear test was performed under dry and wet conditions for a time 4 minutes at loads of 6, 8, 10, 12 and 14 N. The lubricating liquid used in wet condition is called artificial saliva. Its composition is illustrated in Table 4.

Table 4: Artificial saliva composition

Compound	Na2HPO4	NaHCO3	CaCl2	H2O	HCL-1M
Concentration	0.4 g	1.7 g	0.15 g	800 ml	2.5 ml

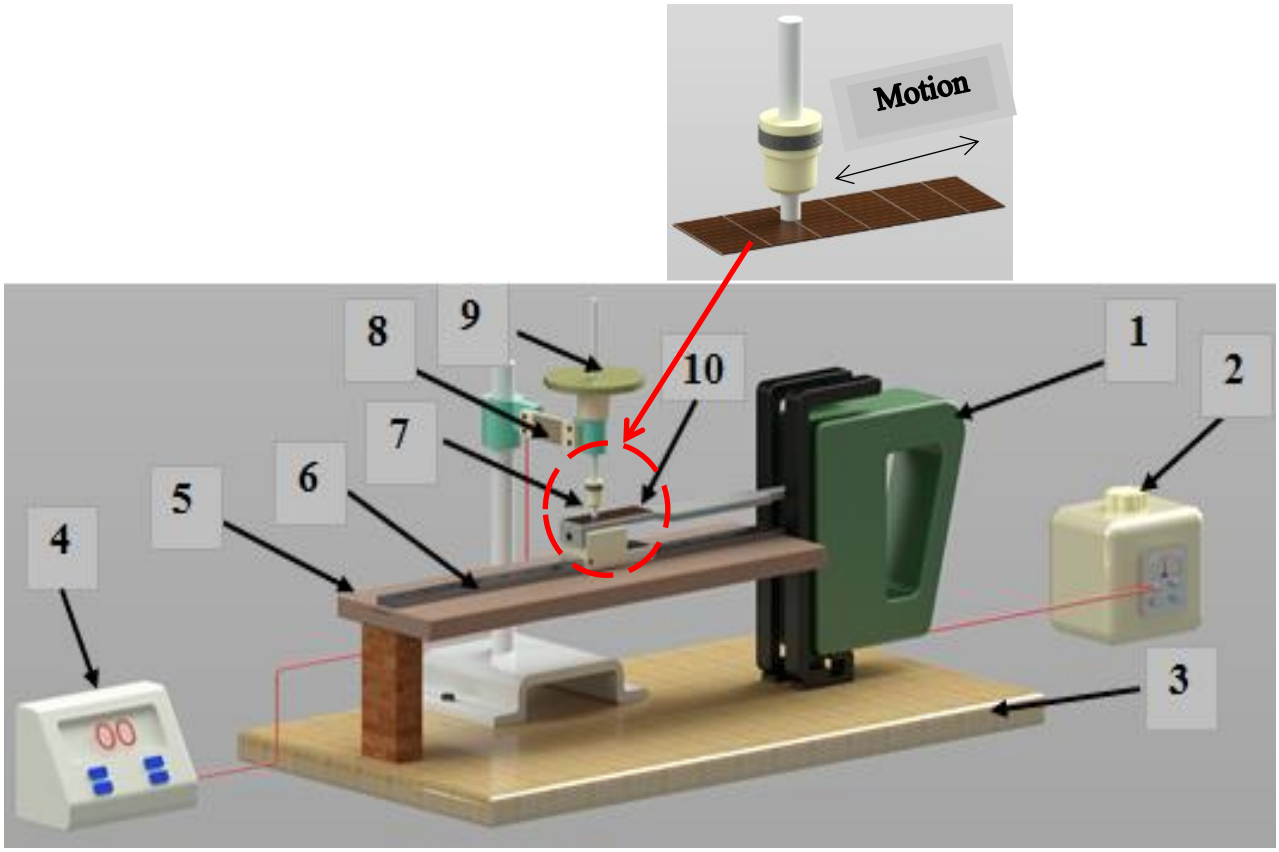

Fig. 6 reciprocating test rig.
1. Motor, 2. Voltage regulator, 3. Base, 4. Friction force screen, 5. Plate, 6. Linear Bearing, 7. Sample, 8. Load cell, 9. Normal Load, 10. Emery Paper

RESULTS AND DISCUSSION

1. Influence of concentration of SiC NFs on wear behaviour

1.1. Dry Conditions

The effect of concentration of SiC nanofibers on the wear of specimens cured with strong mode at 40, 60 and 99 seconds at different loads and dry condition is displayed in Figures 7, 8 and 9 respectively. It can be evident that in these figures the wear first decreased

when SiC NFs increased from 0 wt. % to 0.1 wt. % and then increased when SiC NFs increased from 0.1 wt. % to 0.3 wt. % at all values of normal loads in all figures.
The decrease in the wear up to 0.1 wt. % of SiC nanofibers may be attributable to the homogenous dispersion and higher contact surface of nano fillers with the organic matrix, which improve the strength of the resin, [4]. Therefore, the wear will decrease. The reason for the increase in wear after 0.1 wt. % of SiC nanofibers may be attributed to an increment the concentration of SiC nanofibers. The good adhesion between nanofibres and a composite resin can transfer stress, which is helpful for the improvement of the strength of composite films. However, with increasing the content of SiC nanofibers, agglomerations occurs, that leads to a decrease in the contact between SiC nanofibers and composite resin causing defects in the composites and wear increases. Figure 11 reveals that the hybrid composites cured with strong mode at 99 seconds containing 0.1 wt. % SiC nanofibers exhibit the lowest wear value followed by the hybrid composites containing 0 wt. % SiC nanofibers, and then the hybrid composites contains 0.2 wt. % SiC nanofibers and lastly the hybrid composites containing 0.3 wt. % SiC nanofibers. In other words, the hybrid composites containing 0.1 wt. % SiC nanofibers has a higher resistance to wear then the hybrid composites resin containing 0, 0.2 and 0.3 wt. % TiO_2 nanoparticles.

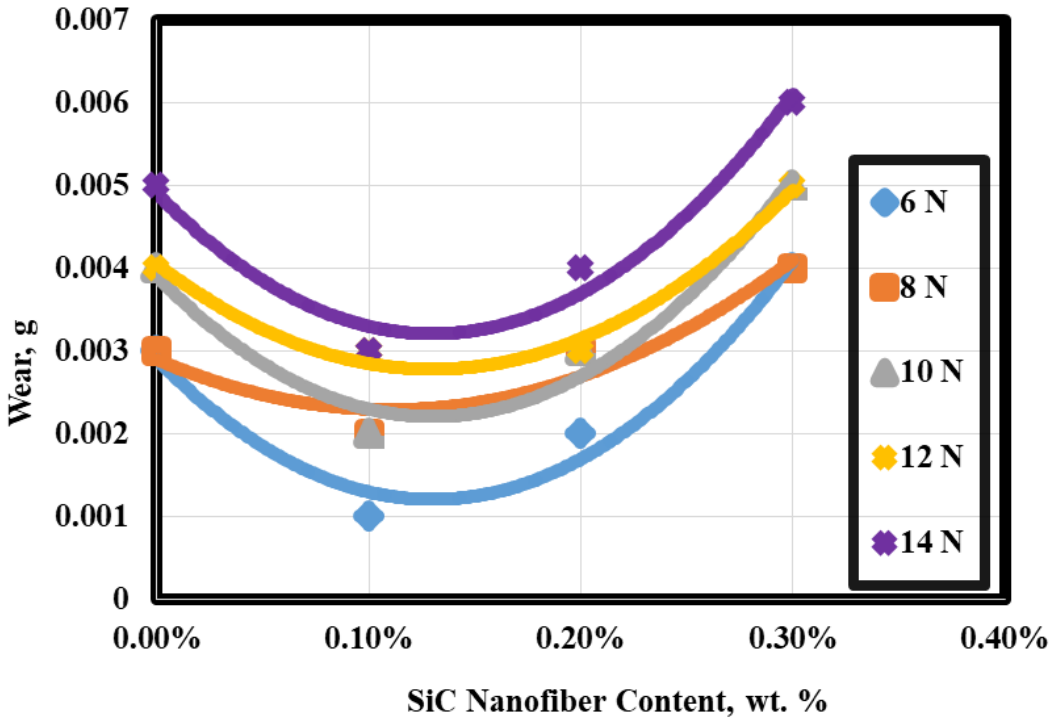

Fig. 7 Effect of concentration of SiC nanofibers on the wear of specimens cured at 40 seconds at different loads and dry condition.

3.1.2. Wet Conditions

The effect of concentration of SiC nanofibers on the wear of specimens cured with strong mode at 40, 60 and 99 seconds at different loads and wet condition is displayed in Figures

10, 11 and 12 respectively. It can be evident that in these figures the wear first decreased when SiC NFs increased from 0 wt. % to 0.1 wt. % and then increased when SiC NFs increased from 0.1 wt. % to 0.3 wt. % at all values of normal loads in all figures.
The decrease in the wear up to 0.1 wt. % of SiC nanofibers may be attributable to the homogenous dispersion and higher contact surface of nano fillers with the organic matrix, which improve the strength of the resin in addition to using artificial saliva that works as a lubricant and so it led to decreas in wear. The reason for the increase in wear after further increase of SiC nanofibers may be attributed to the inhomogeneous dispersion of SiC nanofibers in the resin and the increase of the concentration of SiC nanofibers causing more agglomerations. The contact between SiC nanofibers and composite resin decreased causing defects in the composites by acting as flaws in the resin, so the wear increased. Figure 14 reveals that the composites cured with strong mode at 99 seconds containing 0.1 wt. % SiC nanofibers exhibit the lowest wear value. In other words, the composites cured with strong mode at 40, 60 and 99 seconds at different loads and wet condition containing 0.1 wt. % SiC nanofibers have higher resistance to wear than the others that cured with strong mode at 40, 60 and 99 seconds at different loads and dry condition.

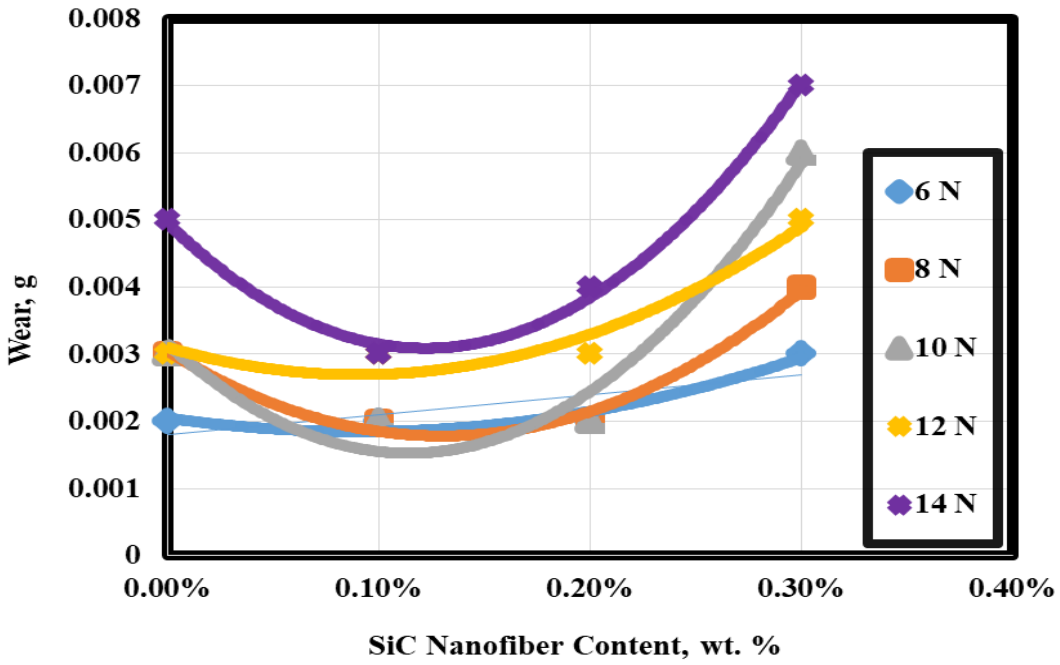

Fig. 8 Effect of concentration of SiC nanofibers on the wear of specimens cured at 60 seconds at different loads and dry condition.

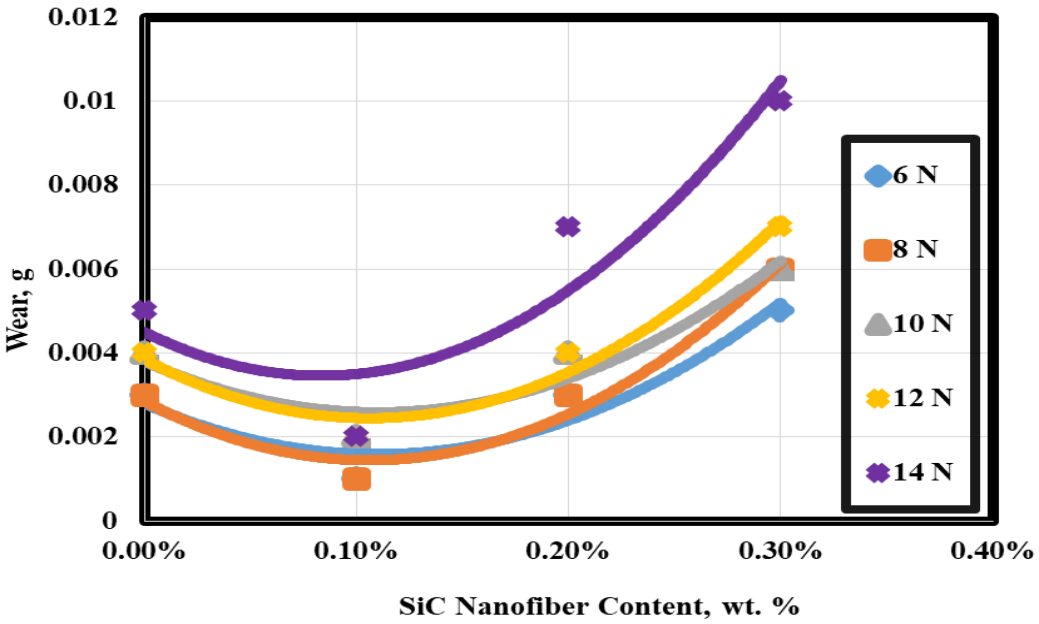

Fig. 9 Effect of concentration of SiC nanofibers on the wear of specimens cured at 99 seconds at different loads and dry condition.

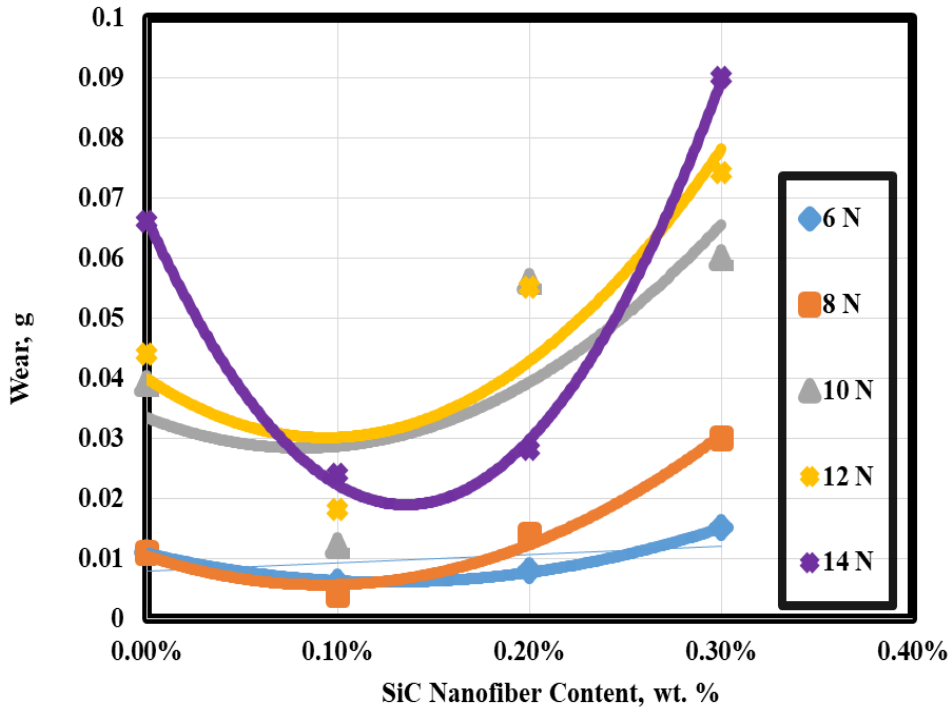

Fig. 10 Effect of concentration of SiC nanofibers on the wear of specimens cured at 40 seconds at different loads and wet condition.

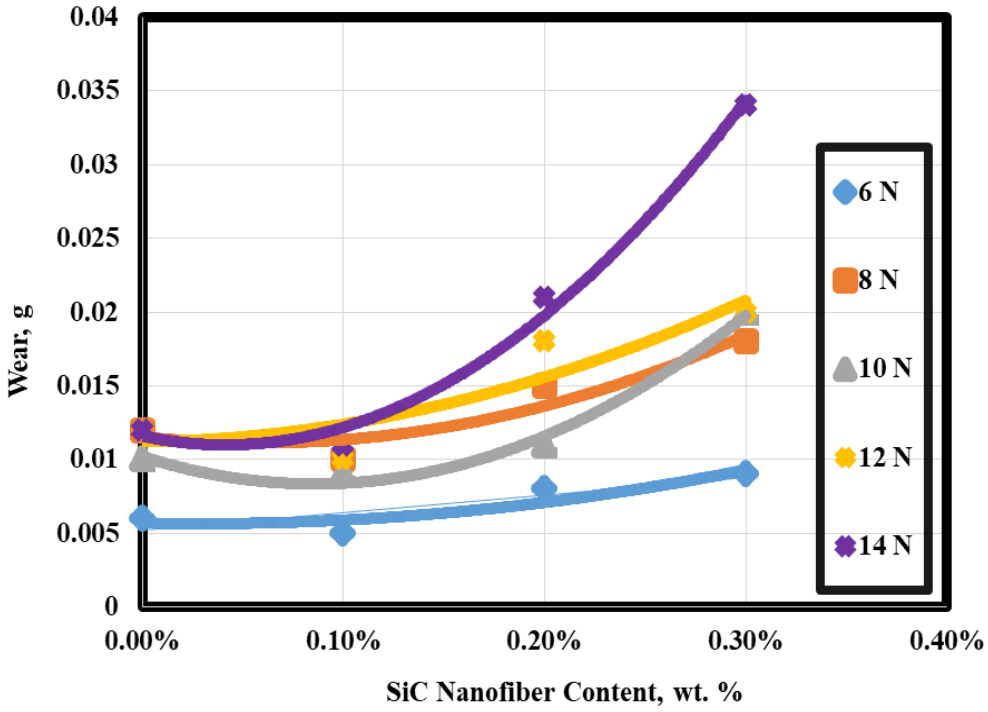

Fig. 11 Effect of concentration of SiC nanofibers on the wear of specimens cured at 60 seconds at different loads and wet condition.

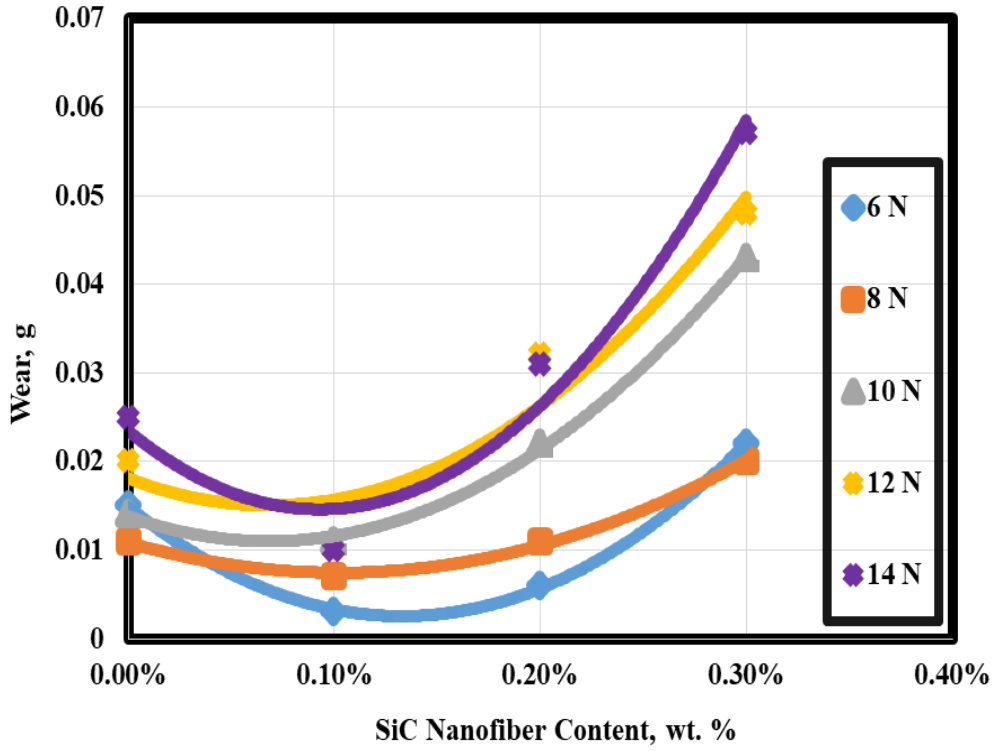

Fig. 12 Effect of concentration of SiC nanofibers on the wear of specimens cured at 99 seconds at different loads and wet condition.

TOPOGRAPHY OF THE WORN SURFACES

To study the wear mechanisms, some worn surfaces were scanned after sliding against emery paper (1000 grit size). The worn surfaces topography examined by electron microscope with magnifications of up to about 200x. Figure 13 gives detailed image of the wear marks on composite resin filled with (SiC NFs), which is evident that the wear tracks formed through surfaces of samples. It can be clearly observed that in the contact interface of specimens there were less mark pits on worn surface of the specimen filled by 0 wt. % SiC NFs as shown in figure (13 O). On the other hand, it can be noticed from Figure (13 A) that specimen containing 0.1 wt. % SiC NFs exhibits the smoothest surface, therefore this content gave the best wear resistance. Consequently, the dispersion of SiC NFs content through the composite resin is a key factor in the surface roughness smooth and in the effectiveness of the wear resistance ability. While, the increasing of filler amount above 0.1 wt. % SiC NFs has a reverse action that the wear tracks returns to increase, where the figures (13 B) and (13 C) show the spread of the wear tracks and grooves on the worn surface of specimens containing0.2 and 0.3 wt. % SiC NFs respectively.

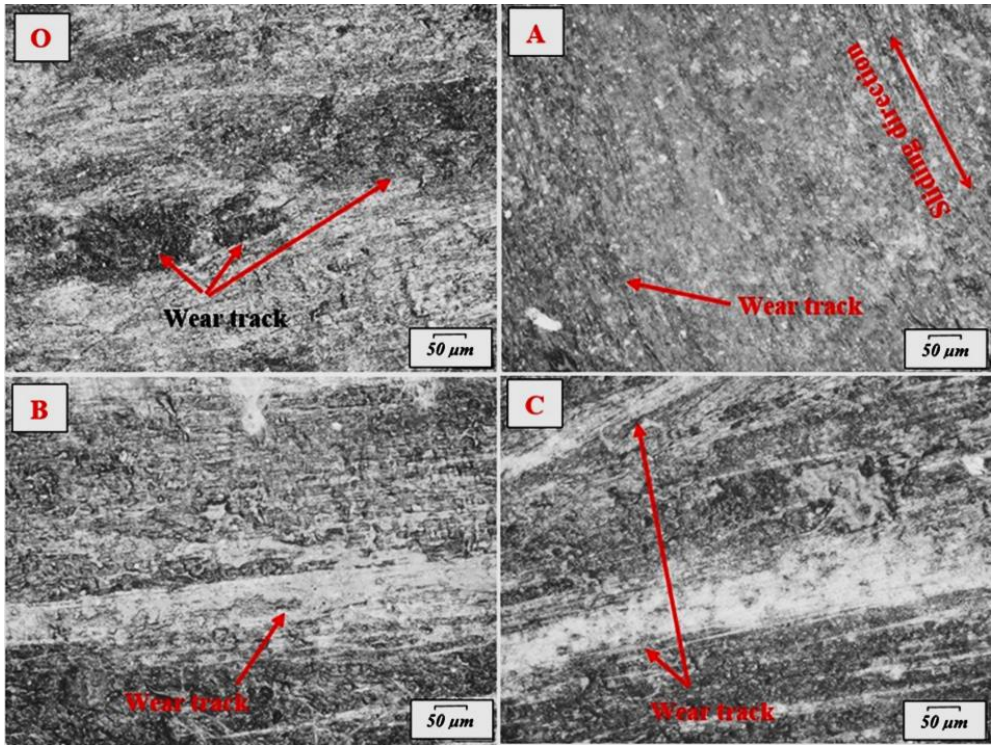

Fig. 13 Optical images of worn surfaces of hybrid composite resin filled with (O) 0 wt. % SiC NFs, (A) 0.1 wt. % SiC NFs, (C 0.2 wt. % SiC NFs, (B) 0 wt. % SiC NFs.

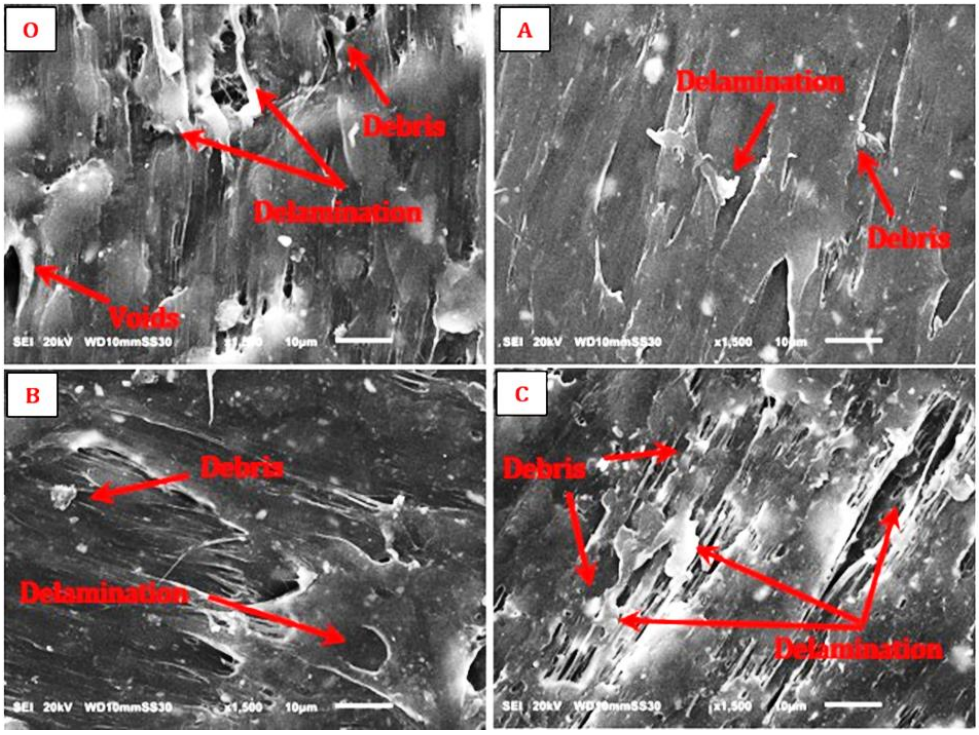

Fig. 14 SEM images of worn surfaces of hybrid composite resin filled with (O) 0 wt. % SiC NFs, (A) 0.1 wt. % SiC NFs, (C 0.2 wt. % SiC NFs, (B) 0 wt. % SiC NFs.

The wear mechanism induced during the test was inspected via Scanning Electron Microscope (SEM). Figure 14, investigated that the morphology of the rubbed surfaces varied with the SiC NFs content. Specimens containing 0, 0.2 and 0.3 wt. % SiC NFs respectively exhibited many delamination layers, voids and wear debris due to the ploughing of their rubbed surfaces, which in turn led to an increase in the weight loss as shown in Fig. 14 (O, B, C). The surface morphology of the specimen containing 0.1 wt. % SiC NFs appeared relatively smooth; this could be due to the improvement in the strength and hardness of the nanocomposites. As a result, there were fewer deteriorated layers, reducing the weight loss.

CONCLUSIONS

The results showed that, the wear resistance of the hybrid composite resin and dental nanocomposite resin depended on the curing times and concentrations of SiC NFs.
From the experimental work, the following points can be concluded:
1. The composite resin cured at 99 seconds gives the high wear resistance.
2. The composite containing 0.1 wt. % SiC NFs and cured at 99 seconds appears to exhibit significantly the highest resistance to wear, so it is recommended.
3. The wear resistance decreased with increasing the normal load.
4. The wear resistance for all specimens increased up to 0.1 wt. % SiC NFs , then decreased with increasing SiC NFs contents .
5. The composite containing 0.3 wt. % SiC NFs gives the lowest wear resistance.

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