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Wear Properties of [Alumina – Zirconia- Titania] / PMMA Nanocomposite for Denture Base

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***Abstract* - In the field of dental and filling industries, the matrix used in the preparation of polymeric composites are supposed to be subjected to various types of different mechanical stresses that lead to fracture or crushing of the teeth, in addition to their exposure to wear as a result of friction in the periodic process of cutting, tearing, crushing and grinding food. Therefore, the effect of using ceramic nanoparticles in cementing a poly methyl methacrylate (PMMA) on the tribological properties was studied for the purpose of obtaining a material with good mechanical specifications for use in the manufacture of fillings, denture base, bridges and artificial teeth. Wear and friction characteristics of PMMA as a matrix reinforced by nanoparticles in weight percentage of Zirconia (30% ZrO_2), Alumina (40% Al_2O_3), and Titania (30% TiO_2) to gate the phase ($Zr_{0.3}Al_{0.97}Ti_{0.47}O_3$) in terms of different volume fractions were studied. Synthesis of nanocomposites specimens was performed by technological processes including thermal drying, mechanical mixing, heat treatment, ultrasonic dispersion for reinforcing nanoparticles ($Zr_{0.3}Al_{0.97}Ti_{0.47}O_3$) in (50 – 70) nm followed by composited with PMMA matrix in aluminum molds. A pin-on-disc technique was used to measure wear and friction coefficients with the smooth 1045 steel disc rotate with the speed (120) rev/min with a diameter (4) cm as a counter face. The test was done with constant loading of 90N for (one hour). Hardness, density, and optical microscope images were employed to help in the discussion of the results. Results show that the friction (μ) and wear (K) coefficients were enhanced as a function of increasing volume fraction of ($Zr_{0.3}Al_{0.97}Ti_{0.47}O_3$), which reached ($\mu$ = 0.008591) and (K = 0.92618 x 10^{-7}). It can be concluded from the results that the ($Zr_{0.3}Al_{0.97}Ti_{0.47}O_3$ - PMMA) nanocomposites were suitable as denture bases in dental applications.**

***Keywords*:** Denture base, Friction, Nanocomposites, PMMA, Titania, Wear, Zirconia.

INTRODUCTION

Exposure to losing a tooth or some of it, has a great impact on daily life as it hinders a person's activity and causes many problems and troubles, these problems may be related to appearance or difficulty in speaking or eating and causing some pain, and recently many methods have been developed that help gets rid of this problem, for example, there is a group of dental fixtures that replace lost teeth by placing artificial teeth in their place, and for these fixtures there are many and many types that are commensurate with all aspects of the problem of tooth loss.

Movable dental fixtures are the fixtures that every person can remove and re-install on their own, and they have different types of materials that go into their manufacture as basic material, as each patient needs to create a dental prosthesis specific to their condition estimated by the doctor, and the moving dental fixtures do not differ from each other only in terms of material manufacturing, but there are also multiple differences in terms of form, for example, or the method of use, which is subject to the requirements of each case individually, and these types are: complete movable dental fixtures, instant movable dental fixtures, partial movable dental fixtures and additional removable dental fixtures [1]. The material from which the movable dental prosthesis is made varies according to several factors such as the patient's need, the cost of manufacture, etc., and among these materials: acrylic movable dental fixtures, movable dental fittings made of acrylic and metal, and flexible movable dental fittings [2].

Fixed dental fixtures are known as crowns or dental bridges, and they are formulations that are fixed once by the doctor and cannot be removed after that except in dental clinics. They are resorted to using them according to specific cases estimated by the doctor and then consult with his patient, and these fixtures have a number of the types as follows [3 - 5]: dental fixtures made of porcelain, metal dental fixtures, E-Max formulations, and Zircon dental fixtures. Zircon dental fixtures compositions are made of zircon metal internally and externally and are often covered with porcelain to improve their aesthetic appearance. They are more durable than porcelain fittings with a metal mold and E-Max fixtures, so they are preferred for use in dressing molars, and they are free of minerals. It helps in avoiding many allergic problems and infections, and it is more expensive than others, and its disadvantages are the inconsistency of its colors with the natural teeth, the difficulty in detecting the problems occurring in it, and also the possibility of contact with the teeth.

Many of the modern technologies require materials with unusual combinations of properties that cannot be met by conventional metal, alloys, ceramics, and polymeric materials [6]. In our current study, a composite material with mechanical and tribological properties suitable for dental technology applications was used. So the choice was poly methyl methacrylate (PMMA), which is generally used as a modest thermoplastic polymer for dental applications.

PMMA materials have been routineness used with various developments since that it is viable with the tissue of a person. For the explanation that its clarity and bio-viable, PMMA materials are significant with optometry to substitute the intraocular focal point for waterfall patients. PMMA is used to resemble bone concrete in a muscular medical procedure. The modulus of adaptability is equivalent to the regular bone, and it gives a more typical inclination to the patient as an inverse of metallic other option [7, 8, 9].

In our study, mechanical and tribological properties of the PMMA matrix were improved by using three reinforced materials: alumina, Zirconia, and Titania. Alumina is a ceramic material with thermally stable and structurally stable properties that can be used in various fields and applications. The second material that was chosen to be among the components of the nano-mixture used in this study is zirconia. Zirconia is considered one of the materials approved as one of the components in use for applications of fillings, bridges, and crowns for fixed or movable teeth, and even more than that in one of the components of prosthetic materials for different types of bones. Among many materials, titanium dioxide (Titania) was used as a compact material with zirconia. Titanium dioxide (TiO_2) is low density, high strength-to-weight ratio, great biocompatibility, and further developed erosion obstruction with great versatility and mechanical properties. Titanium dioxide (Titania) is normally clung with oxygen, thermal stability, incombustible and dissolvable.

Wear rate (W_R) and wear coefficient (K) is measured by equations [10, 11, 12]:

$$W_R = \frac{\Delta W}{S_D} \qquad (1)$$

$$K = \frac{\Delta V . H_V}{S_D . L} \qquad (2)$$

Where: ΔW, mass loss (gm), ΔV, volume loss (m^3), H_V**,** Vickers hardness (N / mm^2), L, load (N), and S_D**:** is the distance (m). The friction coefficient equation [13, 14]:

$$\mu = \frac{Q}{r \times L} \qquad (3)$$

Where: Q, the torque of friction (m.N) and r, is the radius of stainless steel disc in (m).

Numerous literatures has been published on the subject of dental and the use of the powder metallurgy method in addition to the method of preparing nanocomposites using the mold casting technique and studying the tribological properties of the different systems for manufacturing denture base, where these researches provided important information in support of the following research [15 - 20].

MATERIALS AND METHODOLOGY

Poly methyl methacrylate could be conveyed like a hard, strong, however delicate material, with a glass transaction of temperature at 105°C. PMMA materials have better mechanical force, appropriate compound obstruction, and extremely fine climate opposition. PMMA materials have suitable handling attributes, magnificent thermoforming and could be specially made with colors, fire extra deferring, UV absorptive added substances, and scratch safe coating [21, 22, 23].

Alumina it is a very suitable material for use as a component of fillings, bridges dentures, or movable denture bases. Therefore, it was chosen to be one of the components of the nano-mixture in this study [24, 25, 26]. Note that the Alpha-type alumina material with mechanical properties and high thermal insulation was selected.

Zirconia is a quaternary or binary oxide of zirconium and is in the form of a white crystalline powder with a monoclinic crystalline structure at room temperature. A shift in the structure to the quaternary crystal system or the cubic system when the temperature is raised, and here the volume expansion resulting from this transformation leads to great stresses on the crystal causing cracking, and this is why other materials are added to zirconia in order to stabilize the phases [27, 28, 29].

Also, TiO_2 is practical and artificially steady, with great optical properties, warm dependability, a high refractive list, and inadequacy of absorbance of apparent light. Dental prostheses may incorporate (TiO_2) as a shading specialist; half and half materials going from yellowed-straightforward to red tones might be acquired utilizing TiO_2 into a given PMMA detailing [30, 31, 32].

Powder metallurgical technique [33, 34] was used to obtain the fine and excellent mixture of Zirconia (30% ZrO_2), Titania (30% TiO_2), and Alumina (40% Al_2O_3) for (5) hours. In the presence of ethanol coupling with an ultrasonic technique for (30) minutes, the mixture was dispersed. The mixture at 100 ^{0}C in an electric oven for (2) hours was dried. The final step to gate nano- ($Zr_{0.3}Al_{0.97}Ti_{0.47}O_3$) with (50 - 70) nm diameter was gotten using calcination heat treatment at (800) ˚C for (3) hours.

The nano - ($Zr_{0.3}Al_{0.97}Ti_{0.47}O_3$) with (50 - 70) nm diameter was used for reinforcement of PMMA matrix in terms of different volume fractions (0, 1.5, 3.5, 5.5, 7.5 and 10) Vol.%. Nanocomposites samples have been prepared by ultra- sonicated during a period of time (50) minutes. Finally, the mixture was cast in an aluminum mold (ϕ = 10 mm, l = 60 mm) to be ready for various tests and measurements.

Pin-on-disc was used to gate the wear and friction tests. The counter face smooth 1045 steel disc rotates with the speed (120) rev/min with a diameter (4) cm. The test was done with constant loading of 90N for (one hour). Vickers hardness was used to measure the hardness.

RESULTS AND DISCUSSION

The variation of friction coefficient as a function of volume fraction of the individual and the nanocomposite of PMMA matrix is shown in Figure 1. All specimens show such similar behavior as friction coefficient starts from high values and then settles to fairly low and stable values as the load exceeds (90 N) and up to the seizure point, where the specimen starts to flow viscously. The maximum load that specimen can endure depends on the volume fraction of the added ceramic glass powder ($Zr_{0.3}Al_{0.97}Ti_{0.47}O_3$)) and at a fixed load of (90 N), the friction coefficient values vary as inverse - linear relationship with the volume fraction of ($Zr_{0.3}Al_{0.97}Ti_{0.47}O_3$) added to the PMMA matrix as shown in Figure 1. The high friction coefficient value at low volume faction may be explained by the static electric charges that build upon the test specimen, causing an attraction with the counter disc. This is in line with the attractive theory of sliding polymers [35, 36]. Another reason for the high friction coefficient values may be due to the action of the asperities of the rubbing surfaces, which are presumable large at low loads.

But at the median volume fraction, where the friction coefficient values have dropped to values that are about half of the original values, may be associated with the formation of a thin film layer from the test of the specimens on the counter disc as a result of the frictional heating. This would cause the sliding surfaces to be more effective. For the high volume fraction, the low friction coefficient values of the composite specimens are due to the lubrication nature of the ceramic glass powder ($Zr_{0.3}Al_{0.97}Ti_{0.47}O_3$). As the volume fraction of ceramic glass powder ($Zr_{0.3}Al_{0.97}Ti_{0.47}O_3$) is increased, the fraction of its interlocking surfaces becomes larger; this leads to a further decrease in the friction coefficient values, as shown in figure 1.

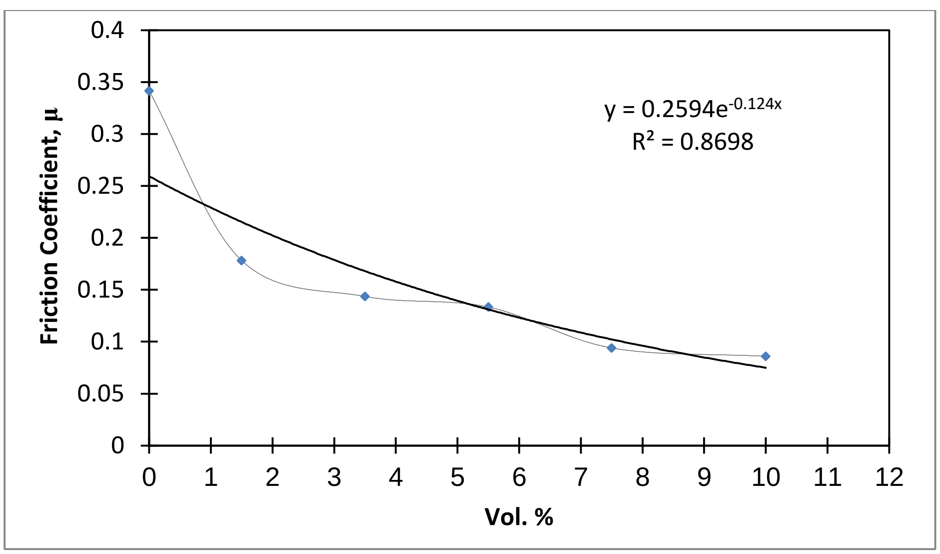

FIG. 1
VARIATION OF FRICTION COEFFICIENT AS A FUNCTION OF ($ZR_{0.3}AL_{0.97}TI_{0.47}O_3$) VOLUME FRACTION OF THE NANOCOMPOSITE OF PMMA MATRIX.

The variation of wear coefficient as a function of volume fraction of the ceramic glass nanopowder ($Zr_{0.3}Al_{0.97}Ti_{0.47}O_3$) - PMMA nanocomposite was illustrated in Figure 2. The ceramic glass nanopowder ($Zr_{0.3}Al_{0.97}Ti_{0.47}O_3$) – PMMA composites show a big drop in the coefficient of wear with increasing volume fraction, but it reached semi-constant values above 7.5 Vol.%. This agreement with the previously reported results informed us that the wear coefficient was decreased rapidly during the run-in and achieved a steady value for continued sliding [37]. The wear coefficient values at higher volume fractions were in steady-state. It is interesting to note that the wear of the largest volume fraction of nanopowder ($Zr_{0.3}Al_{0.97}Ti_{0.47}O_3$) composite specimen being the smallest at the moderate loads. The results can be summarized as illustrated in Table 1.

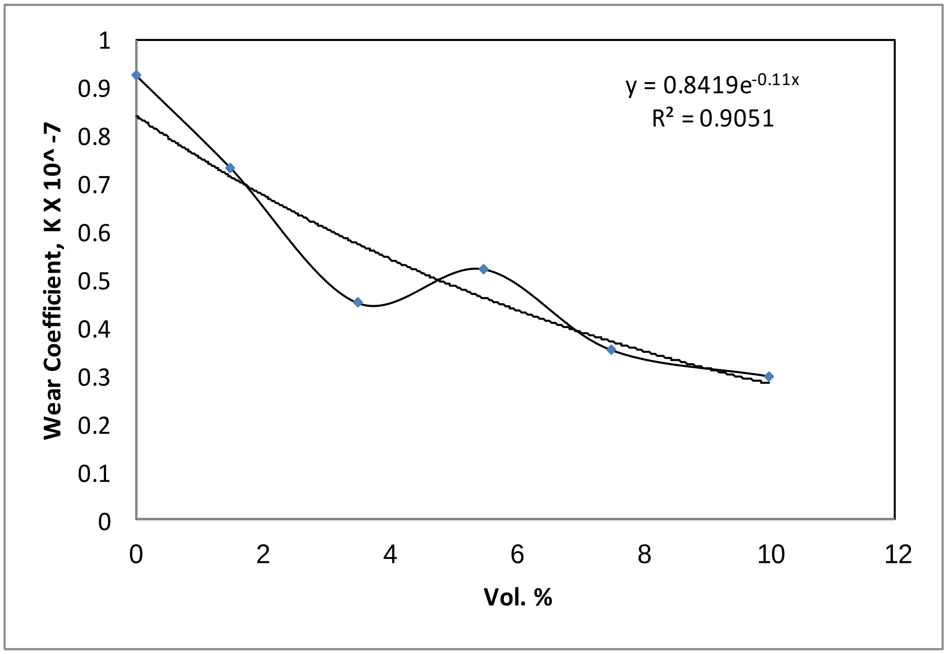

FIG. 2

VARIATION OF WEAR COEFFICIENT AS A FUNCTION OF ($ZR_{0.3}AL_{0.97}TI_{0.47}O_3$) VOLUME FRACTION OF THE NANOCOMPOSITE OF PMMA MATRIX.

TABLE 1

RESULTS OF FRICTION AND WEAR COEFFICIENTS AS IN TERMS OF VARIATION OF VOLUME FRACTION

Vol. %	μ	***K x 10^ - 7***
0	0.341721	0.92618
1.5	0.178219	0.73161
3.5	0.143607	0.45001
5.5	0.133399	0.52013
7.5	0.09394	0.35216
10	0.08591	0.29649

Visual examinations show that the film progressed from a dull matte finish to the high gloss appearance characteristic of burnished ceramic glass nanopowder ($Zr_{0.3}Al_{0.97}Ti_{0.47}O_3$). Optical SEM microscopy of typical wear surfaces of (10, 7.5, 5.5. 3.5, 1.5, and pure PMMA) volume fraction of ceramic glass nanopowder ($Zr_{0.3}Al_{0.97}Ti_{0.47}O_3$) produced during sliding are shown in Figures 3 - 8.

At the largest volume fraction of ($Zr_{0.3}Al_{0.97}Ti_{0.47}O_3$) nanoparticles (10Vol.%), Figure (3) shows the development of smooth surfaces at heavier loads in comparison to Figures (4 and 5) which shows ploughing groves that extend the length of the wear track. It is also evident that the development of smooth surfaces is impaired by lower ($Zr_{0.3}Al_{0.97}Ti_{0.47}O_3$) nanoparticles content coupled with a rise in wear coefficient, as seen in Figures 6 and 7, which can be compared with that of pure PMMA in Figure 8.

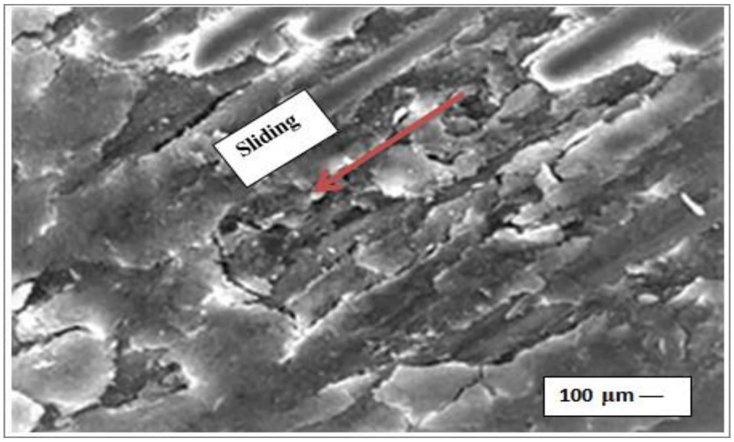

FIG. 3
SEM MICROSCOPY OF WEAR SURFACE OF 10 VOL. % OF CERAMIC GLASS NANOPOWDER ($ZR_{0.3}AL_{0.97}TI_{0.47}O_3$) IN PMMA NANOCOMPOSITE UNDER (500X MAGNIFICATION)

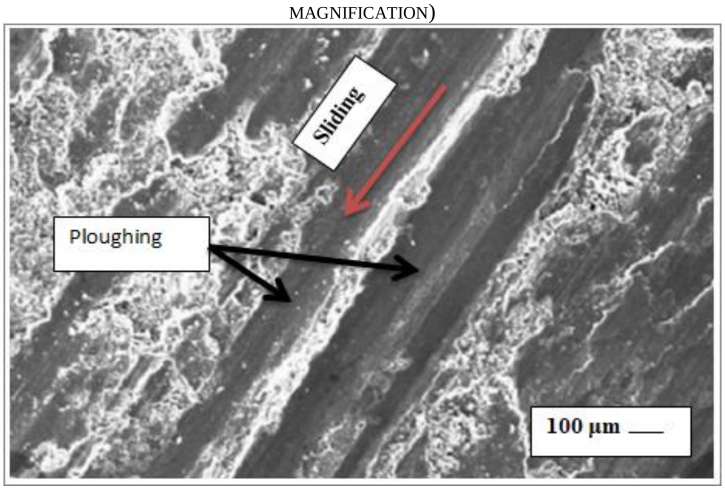

FIG. 4
SEM MICROSCOPY OF WEAR SURFACE OF 7.5 VOL. % OF CERAMIC GLASS NANOPOWDER ($ZR_{0.3}AL_{0.97}TI_{0.47}O_3$) IN PMMA NANOCOMPOSITE UNDER (500X MAGNIFICATION).

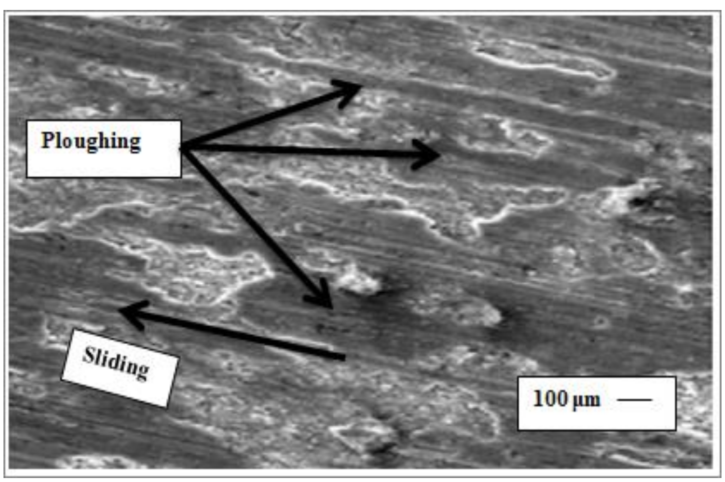

FIG. 5
SEM MICROSCOPY OF WEAR SURFACE OF 5.5 VOL. % OF CERAMIC GLASS NANOPOWDER ($ZR_{0.3}AL_{0.97}TI_{0.47}O_3$) IN PMMA NANOCOMPOSITE UNDER (500X MAGNIFICATION)

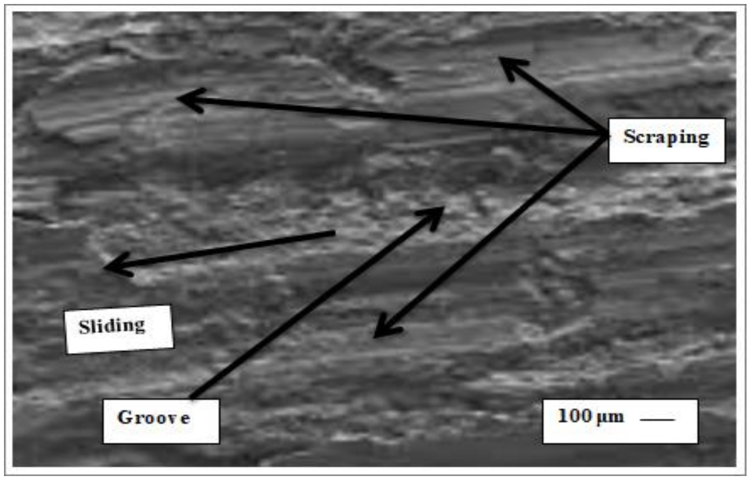

FIG. 6
SEM MICROSCOPY OF WEAR SURFACE OF 3.5 VOL. % OF CERAMIC GLASS NANOPOWDER ($ZR_{0.3}AL_{0.97}TI_{0.47}O_3$) IN PMMA NANOCOMPOSITE UNDER (500X MAGNIFICATION)

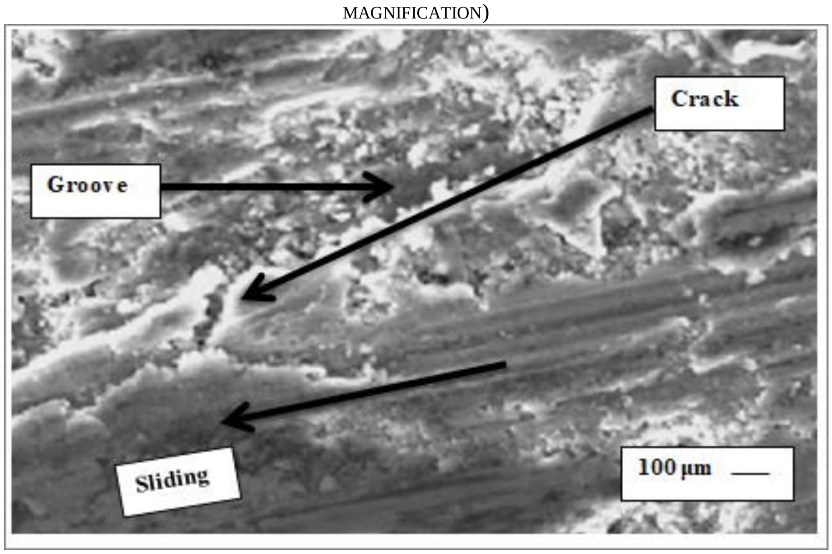

FIG. 7
SEM MICROSCOPY OF WEAR SURFACE OF 1.5 VOL. % OF CERAMIC GLASS NANOPOWDER ($ZR_{0.3}AL_{0.97}TI_{0.47}O_3$) IN PMMA NANOCOMPOSITE UNDER (500X MAGNIFICATION)

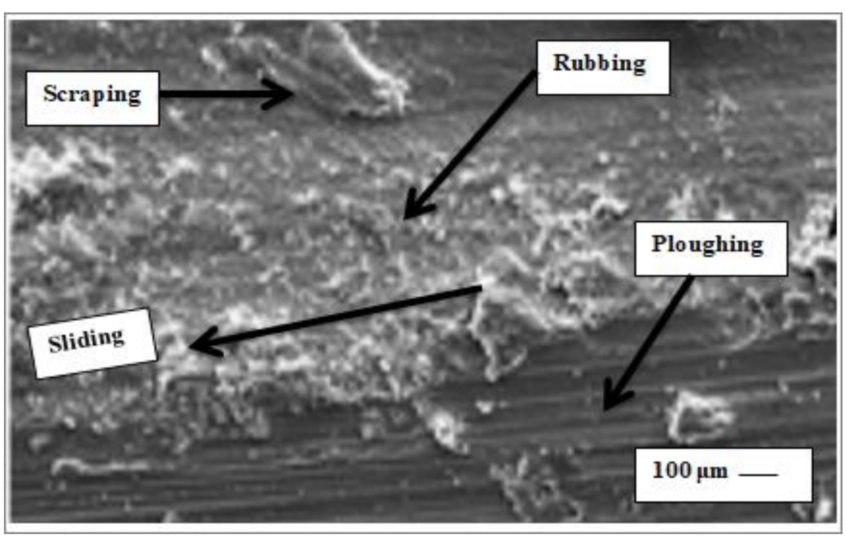

FIG. 8
SEM MICROSCOPY OF WEAR SURFACE OF PMMA SPECIMEN UNDER (500X MAGNIFICATION)

CONCLUSION

Although the coefficient of friction of the ceramic glass nanopowder ($Zr_{0.3}Al_{0.97}Ti_{0.47}O_3$) - PMMA nanocomposite is moderate, which is obviously very suitable as denture base material, it can be serving the application in the points of mechanical contact regions (position filling element) for the dental field. Topographies of warning surfaces of highest volume fraction of ceramic glass nanopowder ($Zr_{0.3}Al_{0.97}Ti_{0.47}O_3$) develop smooth the glass surface by low wear coefficient in comparison with the lower ceramic glass nanopowder ($Zr_{0.3}Al_{0.97}Ti_{0.47}O_3$) content that is characterized by the presence of the ploughing groves along the wear track. Minimum wear coefficient values show by the high ceramic glass nanopowder ($Zr_{0.3}Al_{0.97}Ti_{0.47}O_3$) means longer service life.

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