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HEAT TREATMENT OF POLYMETHYL METHACRYLATE DENTURE BASE

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ABSTRACT
It is known that fracture of the polymethyl methacrylate (PMMA) denture base is critical clinical problems. It is essential to develop the mechanical properties of the denture base. One of the methods to improve the mechanical properties is the heat treatment. Heat treatment includes annealing, normalizing and quenching. The influence of heat treatment of PMMA denture on the friction and wear is studied in the present work. PMMA has been heated up to 80 °C for 4 hours then air, water and furnace cooled. Adhesive and scratch wear tests have been performed to investigate the wear resistance of the heat treated PMMA.

It was found that annealed PMMA showed the lowest values of friction coefficient, while quenched PMMA in water displayed the lowest values. Besides, annealed PMMA showed the lowest wear values, where annealing enhanced the crystallization of PMMA so that the resistance to wear increased. When the crystallinity of the polymer increases, the strength and brittleness increases. Annealing of PMMA increases crystallinity and decreases plasticity. Friction and wear of water quenched PMMA showed the highest values due to the hardness decrease.

KEYWORDS
Scratch, adhesive wear, friction, heat treatment, polymethyl methacrylate.

INTRODUCTION
PMMA is used for manufacturing dentures that are exposed to fatigue, flexural, and impact stresses. It was found that the performance of PMMA can be improved by incorporating nanoparticles of ceramics. Filling PMMA with nanoparticles of aluminum oxide (Al_2O_3), titaniun dioxide (TiO_2) and zirconium oxide (ZrO_2) develops the mechanical properties such as tensile and compressive strength as well as micro-hardness, [1]. Heat treatment of polymethyl methacrylate (PMMA) significantly influences its properties, where heat treatment below the glass transition temperature (Tg) improves hardness. The PMMA filled by silica heat-treated up 180 °C, [2], exhibited higher miscibility compared to untreated materials.

Heat treatment of polymers was used to modify and widen their application. It was found that heat treatment of polyamide (PA) developed its tribological properties, [3], due to the crystal phase increase in the polyamide matrix, leading to the increase of the elastic part of polyamide viscoelasticity. It was found that surface structure of polyaniline (PANI) ultra thin films was studied as a regarding the thickness and annealing time. It was revealed that annealing of some polymers with solvent vapor produces a coating. The phase separation of thin film of polystyrene, (PS), and PMMA blends upon annealing was inspected by X-ray microscopy, [4 - 8], was used to measure the morphology of thin gold (Au) coatings sandwiched between two PS layers was inspected by X-ray reflectivity. The morphology of samples was influenced by annealing, [9]. It was concluded that annealing promotes spherical shapes for the Au particles.

Polymers are widely applied as thin films of low dielectric interlayers and insulators, [10 - 13]. Several studies have focused on the performance of coating polymer substrates by metallic particles, where the physical properties at the metal/polymer interface were complex, [14 – 16]. When the composites were heated above Tg of the polymer substrate, the Au particles tend to diffuse into the matrix of the polymer substrate, [17]. The morphology of polymer composites during annealing depended on the metal particle size.

Heat treatment strongly affected the behavior of glassy polymers. The quenched samples of polyvinyl chloride (PVC) exhibited uniform deformation in tension while the annealed ones showed necking. The effect of heat treatment on the behavior of PS and PMMA during compression and tensile tests was investigated, [18]. Besides, it was observed that the microhardness of polymers decreased as cooling rate increased, [19]. The microhardness of PA coatings reinforced by metallic granulates was measured to study their effect on the cooling rate during preparation. While addition of graphite, molybdenum disulphide, bronze, tin and lead particles to polymers reduced friction and wear, [20], where favorable wear resistance was provided due their influence on the cooling rate of the polymers during preparation.

The change of cooling rate during the production process of PA affected its degree of crystallization that influences the mechanical properties. It is believed that fine silica dust in PA matrix can control the nucleation, increase tensile strength as well as hardness and reduce the ductility. It is necessary to consider the effect of the cooling rate from the surface to the centre on the variation of the morphology of the cast polymer. It is expected that the outer surface will be less crystalline due to the faster cooling rate leading to rapid solidification rate and lower wear resistance, [21]. The friction coefficient and wear of PA were influenced by heat treatment. As the cooling rate increased, both friction and wear decreased, [22]. Slight reduction in friction coefficient and wear was observed at 200 °C of treatment temperature for PTFE.

In the present work, the effect of heat treatment of test specimens of PMMA, on their friction coefficient and wear was investigated.

EXPERIMENTAL

The material of test specimens was PMMA. The test specimens were in the form of flat block of 20 × 20 of 3 mm thickness for abrasive wear, while for adhesive test they

were in form of cylindrical pins of 5 mm diameter and 20 mm length. Before tests, the test specimens were heated up to 100 °C for 12 hours then cooled in water, air and furnace.

The abrasive wear was performed by scratch test rig equipped with a stylus to produce a scratch on the tested surface, Fig. 1. The stylus was TiC of square insert (12 × 12 mm) of 0.1 mm tip radius and 2800 kp/mm^2 hardness. The scratch force was measured by load cell. The friction coefficient was calculated as the ratio of the scratch force to the normal force applied by weights. The applied load values were 2, 4, 6, 8 and 10 N. Wear was evaluated by the value of wear scar width of the scratch, where the width was measured by optical microscope with an accuracy of ± 1.0 µm. The tested surface was cleaned by emery paper (1000 grade) before testing. The test velocity was 2 mm/s manually controlled by turning the power screw feeding the stylus in the scratch direction.

The experiments of adhesive wear were carried out by pin-on-disc test rig, Fig. 2. It consists of a rotary horizontal steel disc of 100 mm diameter driven by variable speed motor. The test specimen of 6 mm diameter and 20 mm length is assembled in the specimen holder attached to the loading lever through load cell to measure friction force. The load is applied by weights. The friction surface of the test specimens was ground by an emery paper [grain size of 100-] before the test. The counter surface of a stainless steel disc of 2 mm thickness and 3.2 µm Ra surface roughness was fastened to the rotating disc. Tests were carried out under 15 N normal loads and 1.5 m/s sliding velocity for 300 seconds. Wear was determined by the the weight loss of the specimens after the test using an electric balance of ± 0.1 mg accuracy.

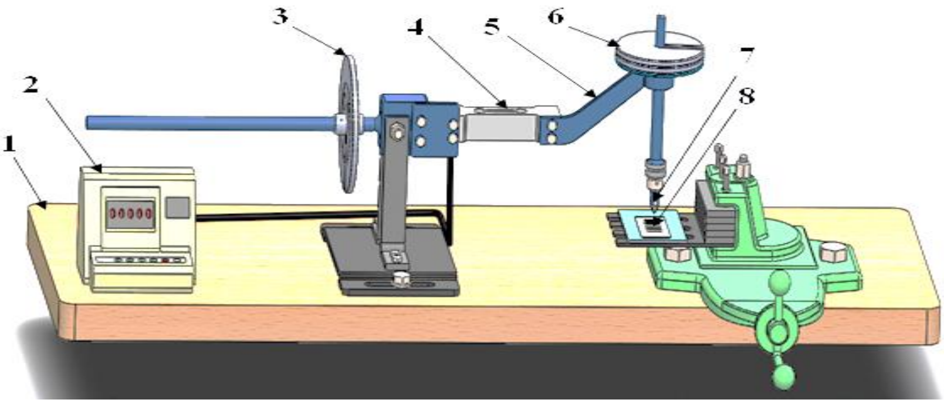

Fig. 1 Scratch test rig,
1. Wooden table, 2. digital screen, 3. counter weight, 4. Load cell, 5. Loading link, 6. Load, 7. Stylus, 8. Test specimen, [23].

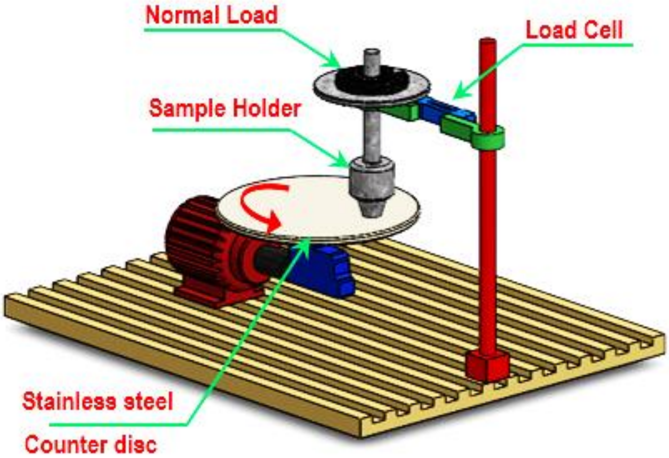

Fig. 2 Adhesive wear test rig, [24].

RESULTS AND DISCUSSIONS

Heat treatment includes annealing, normalizing and quenching. It improves the polymer behavior by increasing strength. It is known that fracture of the PMMA denture base is critical clinical problems. The mechanical properties of the denture base can be modified by adding filling materials to PMMA. Besides, microwave post polymerization improved the flexural strength of denture. PMMA softens when heated above its Tg and hardens after cooling. It was found that the hardness and elastic limit of PMMA changed at annealed temperature of 80 °C.

The results of the friction coefficient and abrasive wear tests are shown in Figs. 3 and 4 respectively. Figure 3 shows the friction coefficient displayed by the scratch of PMMA. As received PMMA showed the highest values of friction coefficient followed by specimens cooled by furnace and air. While specimens quenched in water displayed the lowest values. These results indicated that friction coefficient decreased with increasing cooling rate. This observation confirmed that the quenched test specimens in water had the lowest hardness among the as received, air cooled (normalized) and furnace cooled (annealed) test specimens. It seems that as the hardness decreased the plastic deformation of the polymer increased causing significant decrease in shear strength reducing friction.

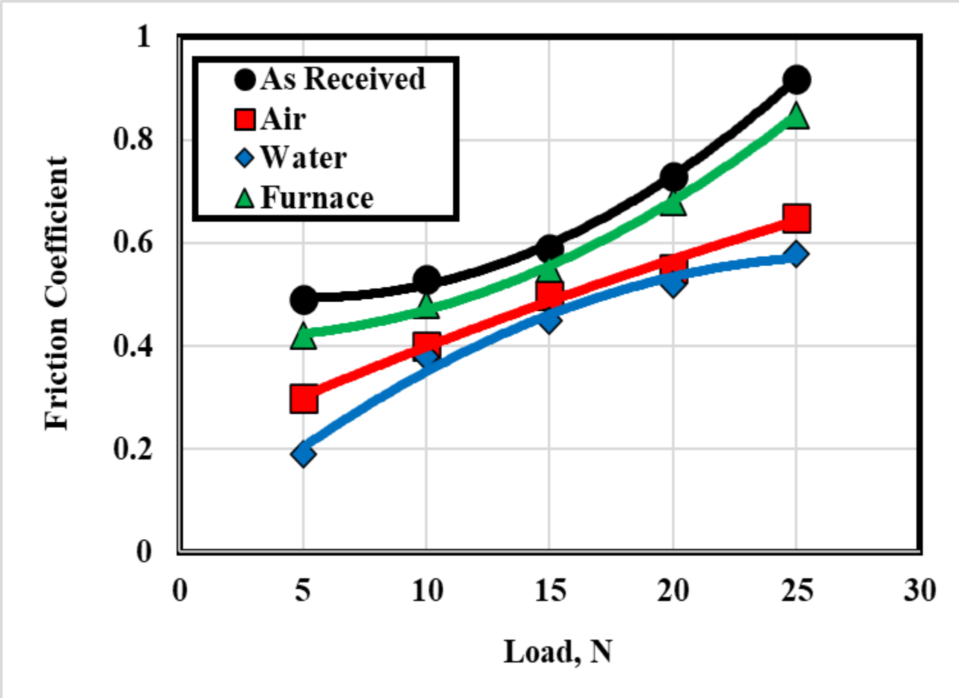

Fig. 3 Friction coefficient displayed by the scratch of PMMA.

Wear of test specimens evaluated by the wear scar width produced by the scratch of PMMA is illustrated as function of the applied normal load in Fig. 4, where wear increased with increasing applied load. As received specimens represented the highest wear values, while annealed PMMA (furnace cooled) showed the lowest wear values compared to test specimens cooled by air and water. It can be indicated that annealing process enhanced the crystallization of PMMA so that the resistance of wear increased. As the crystallinity of the polymer increases, the material becomes strong and brittle. The polymer possesses both crystalline and amorphous regions. Annealing increases crystallinity, and consequently plasticity decreased.

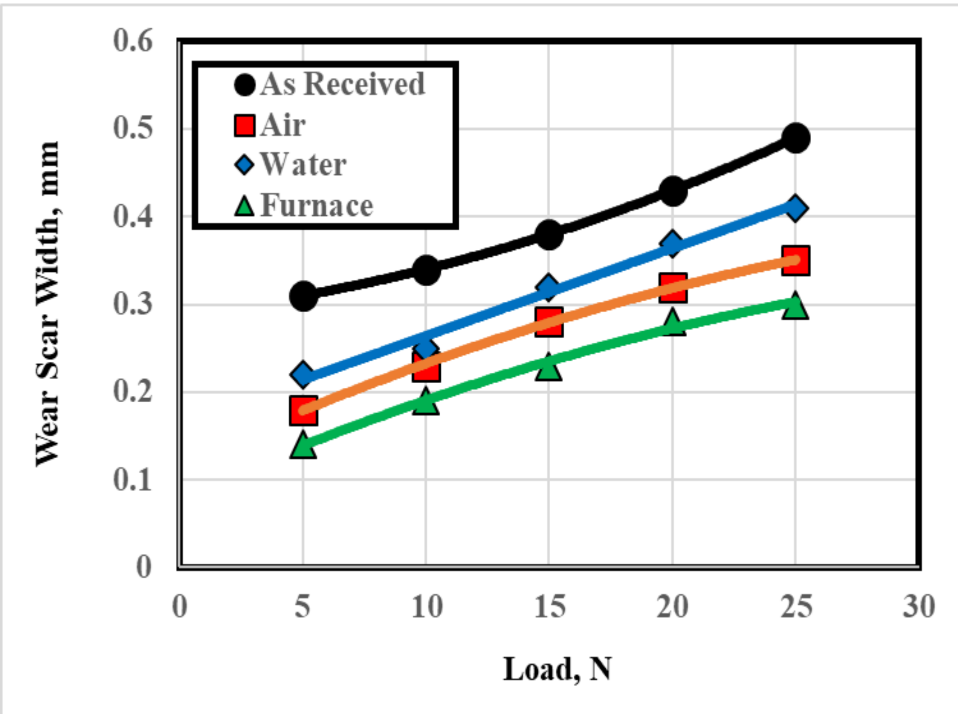

Fig. 4 Wear scar width displayed by the scratch of PMMA.

The results of adhesive wear tests are shown in Figs. 5, 6. Friction coefficient displayed by sliding of PMMA on stainless steel drastically decreased with increasing the applied load, Fig. 5. The friction decrease with load increase may be from the extra heat generated during sliding at relatively higher loads. It seems that a layer of relatively low shear strength was formed on the sliding surface leading to the relatively lower value of friction. Water cooled test specimens represented the highest values of friction due to the hardness decrease leading to the increase of friction. Annealed test specimens that were cooled in the furnace displayed the lowest friction values.

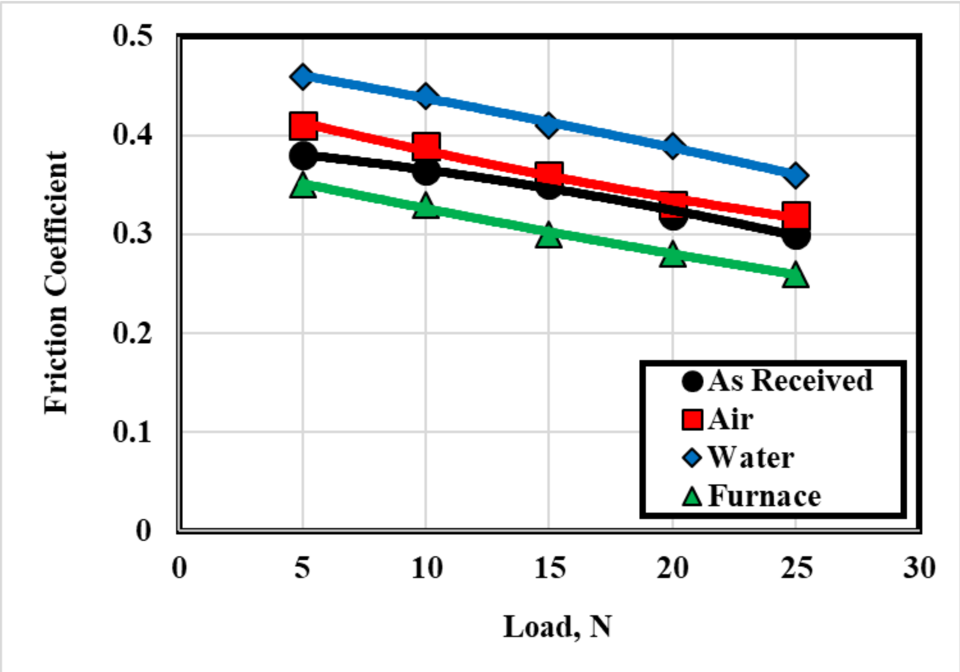

Fig. 5 Friction coefficient displayed by sliding of PMMA on stainless steel.

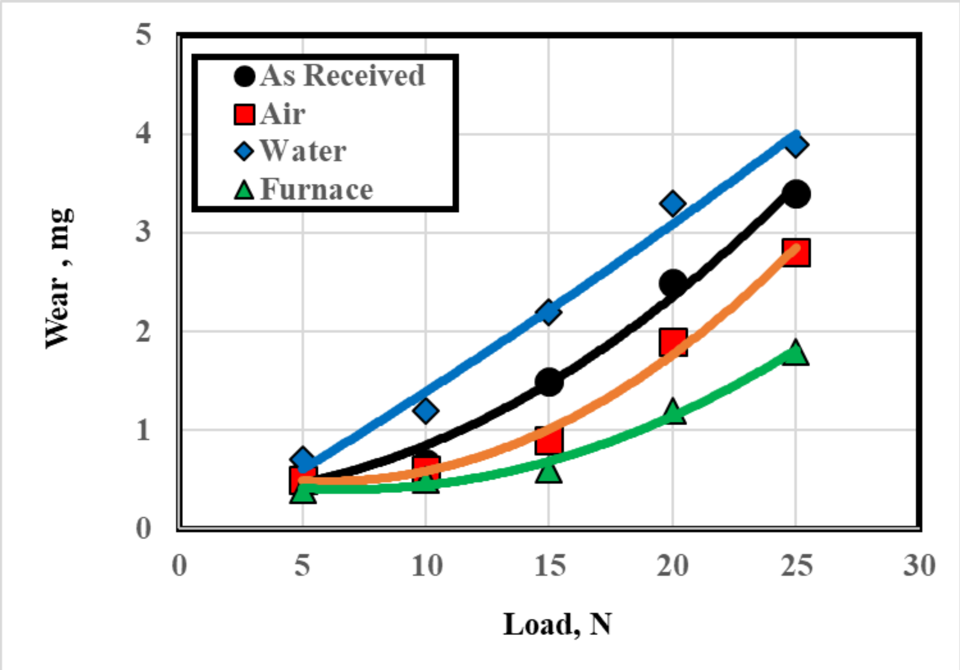

Fig. 6 Wear displayed by sliding of PMMA on stainless steel.

Wear of water cooled PMMA represented the highest values compared to air and furnace cooled ones, Fig. 6. The wear behavior may be attributed to change of the hardness of the tested specimens. As the hardness increases, adhesive wear decreases. When the polymer chain is in a crystalline state the mechanical properties can be enhanced. The degree of crystallinity depends on the crystalline and amorphous regions, where crystalline regions are stiffer than amorphous ones. Heat treatment influences the degree of crystallinity. PMMA has relatively poor tribological properties such as friction coefficient and wear resistance. It is necessary to develop those properties by increasing crystallinity by heat treatment, where PMMA gradually transits from glassy state to elastic state. The enhancement can be explained in terms of that the small molecules in PMMA matrix will continue to participate in the polymerization chain under the effect of temperature that leads to the increase of the molecular weight of PMMA.

CONCLUSIONS

1. Annealed PMMA showed the lowest values of friction coefficient, while quenched PMMA in water displayed the lowest values.
2. Friction coefficient decreased with increasing cooling rate.
3. Annealed PMMA (furnace cooled) displayed the lowest wear values compared to test specimens cooled by air and water.
4. When the degree of crystallinity of the polymer increases, the strength and brittleness of the material increases. Annealing increases crystallinity and decreases plasticity.
5. Quenched test specimens in water represented the highest values of friction due to the decrease of the hardness.
6. Wear of water quenched PMMA showed the highest values due to the hardness decrease.
7. Heat treatment affects the degree of crystallinity.

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