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Assessment of the Mechanical Properties of Hybrid Polymer Composites for Denture Applications

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ABSTRACT: *Acrylic resin is the dominant material that is broadly utilised to produce partial and complete dentures. The exposure of the denture-base acrylic resins to the oral environment as well as storing media for a certain period causes saliva sorption. In this study, composite materials-based polymethylmethacrylate (PMMA) reinforced with 1 wt% of glass fibres and (3, 6 and 9 wt%) yttrium oxide (Y_2O_3) have been prepared, and the addition influence upon some mechanical tests (tensile, flexural, hardness and surface roughness) has been investigated. Afterward, the mechanical properties of composite materials after immersion in artificial saliva for seven days have been evaluated. The results show that the Y_2O_3 percentage is 6%, which possesses a perfect feature. Thus, such a sample may be an encouraging material for achieving the needed properties for denture use. Furthermore, all mechanical properties were decreased after immersion in synthetic saliva.*

Keywords: polymethylmethacrylate, yttrium oxide, polymer composites, synthetic saliva, denture applications

1. INTRODUCTION

The denture base resins have been developed in a lengthy manner since their beginning. Polymethylmethacrylate (PMMA) has been the most common resin since the 1930s and is still in use today. That's attributed to its toughness characteristics due to the sufficient mechanical properties, the stability of dimension, aesthetics, cost-performance, biocompatibility, and the ease of synthesis in comparison with metallic dentures. In spite of the satisfactory characteristics, it's easily vulnerable to breaking through the working owing to

the parameters, like the dynamic masticatory burden as well as the manipulating rehearses among the denture wearers.[1,2]

Fiber strengthening is a virtuous technique for improving the mechanical properties and prolonging the working time of PMMA-based materials.[3] Previous research has shown that glass fibres (GFs) are greater other types of fibre (like Nylon, Polyethylene and Aramid carbon-graphite fibres) that may have poor aesthetics, poor adhesion with the resin matrix, or are unsuitable for dental lab rehearsal.[3–5] On the other hand, GFs are recognised for their bio-compatibility, satisfactory look, and brilliant mechanical characteristics.[5,6] It was documented that the mechanical characteristics of an acrylic composite rely upon the bond between strengthening GFs and the matrix of resin.[6] In recent years, there has been a growing trend towards integrating ceramic fillers into the denture-base acrylic resins to act as a strengthening material. The goal of such a supplement is to produce a composite resin material with further promising mechanical characteristics.[7] Yttrium oxide (Y_2O_3) is the thermodynamically most stable oxide. It's utilised as a coating in the manufacture of metals. Y_2O_3 is frequently utilised with zirconia to form yttria stabilised zirconia (YSZ). It's one of a sequence of metal oxides possessing the same FCC structures. It possesses the usual ceramics features that do not exist in organic or metallic materials, comprising high mechanical strength, high hardness (next to diamond), low electrical conductivity, high stability of temperature stability, resistance to chemicals, and resistance to erosion.[8] Hybrid strengthening regimes have been generated for developing mixes of various metal oxides, fibres, metal oxides, or fillers and fibres stated for producing enhancements in the physical characteristics in comparison with supplementing them individually. The hybrid strengthening can be created via one of the following approaches: The addition of a mix of more than one fibre kind, amalgamating a diversity of ceramics as well as metal oxides, supplementing the mixes of fibres and metal oxides, or utilising the ceramic fillers amalgamation.[9]

Examination of the dental materials and their characteristics at the first step of the digestive method needs the evolution of circumstances that mimic the oral cavity. Saliva is one of the chief constituents of such a field, where numerous reactions take place in the usual circumstances.[10]

Kanie et al. improved some mechanical properties (impact strength as well as flexural strength) of the PMMA strengthened by woven GFs with different layers.[11] Dikbas et al. illustrated the effect of various amount of GFs (2.5%, 3%, 4% and 5%) on the impact properties of PMMA. Results demonstrated that the impact strength was augmented by raising the fibre content, and (5%)

exhibited the optimum value of impact strength.[12] Gad et al. investigated the impact and flexural strengths of a PMMA heat-cured denture base on the hybrid strengthening influences of GFs and zirconium oxide nano particles (Nano ZrO_2) at various ratios. The best properties were achieved at PMMA (2.5%)/Nano ZrO_2 + 2.5% GF mixes.[9]

Jarboo and Alsarraf studied the strengthening effect of the denture-base resin PMMA utilising hydroxyapatite (HA) material, where two sizes of particles (micro as well as nano particles) were employed, and various weight portions (1, 2, 3, 4 and 5) for 50 nm hydroxyapatite and (5, 10, 15, 20 and 25) for 80 μm hydroxyapatite on the resistance to shock, rate of wear, thermal conductivity properties, and hardness. Results revealed that the supreme amalgamation of characteristics seemed to be at the two concentrations of 4% in nano particles as well as at 10% in micro particles.[13] Zidan et al. assayed the solubility and sorption of the high-impact heat-polymerised denture-base acrylic resin (HI PMMA) impregnated with the nano particles of zirconia with different concentrations (0 wt.%, 1.5 wt.%, 3.0 wt.%, 5.0 wt.%, 7.0 wt.% and 10.0 wt.%) later being stowed for 180 days in artificial saliva (AS) and distilled water (DW). The high-impact PMMA exhibited the lowest solubility and sorption in the two media when saturated with low ZrO_2 concentrations.[14] Raj et al. assessed the flexural strength of heat-cured denture-base resin PMMA filler with different weight fractions of nano titanium dioxide (3%, 5% and 7%). It was found the flexural strength decreased after the addition of the nano particles. So, the cytotoxicity was evaluated for pure PMMA and 3% TiO_2/PMMA composites by using human gingival fibroblasts for period times of one and seven days. Results revealed less toxicity, indicating that the resultant composites are biocompatible.[15] Bangera et al. improved the cytocompatibility, mechanical, and tribological properties of polymethylmethacrylate reinforced with nano silver and nano titanium dioxide after treating them with coupling agents.[16]

According to the above literature review, we did not find any study that studied nearly all of the mechanical properties of prepared specimens, nor did we find any study that compared these properties with atmosphere similar to that found in the mouth. So, the main aim of the present work is to assay the hybrid reinforcement material effects of Y_2O_3 and GFs on certain mechanical properties, including surface roughness, hardness, tensile, and bending. Also, the storage effects of the artificial saliva on the properties of the resultant composites.

2. MATERIALS AND METHODS

2.1 Specimens Preparation

The PMMA resin, e-glass random fibres, and Y_2O_3 utilised in the current study were supplied by (Spofa Dental Company, Mowding LTD., UK Company, and Sigma-Aldrich, Germany), respectively. The acrylic resin utilised in this study was blended according to the manufacturer's instructions (3 parts powder to 1 part liquid). The GFs were added to all specimens at a constant weight fraction, which is equal to 1%.

Then, the Y_2O_3 was added at various weight fractions (3%, 6% and 9%), which has purity (99.95%) and a particle size ≤ 25 μm. The amount of particles was selected according to the previous studies. The powder of Y_2O_3 was combined with the acrylic resin monomer and blended by hand, utilising a wood spatula to make sure that the whole powder was distributed consistently inside the monomer of resin. The acrylic resin powder was then added to the solution, and the blending was continued for about 20 minutes, until a consistent mixture was obtained.

The obtained mixtures were arranged in a silicon mould having a dimension according to the required tests. The prepared mixture was poured into the mould, which is nearly half the amount, then the layer of GF was put on, and the remainder of the mixture was continuously poured. After cooling, all specimens were de-moulded to be removed from the mould and cleaned. All tests were achieved at room temperature (23±2). Three specimens were fabricated for each filler ratio. The prepared composites are divided into two groups: (1) storage in distilled water at 37°C for 48 hours and (2) storage in synthetic saliva at 37°C for seven days.

2.2 Preparation of Artificial Saliva

The synthetic saliva solution was made in accordance with the required composition as displayed in Table 1 via dissolution it into (1000 ml) of DW having a 7.4 pH value and blending it utilising a magnetic stirrer till the constituents were totally dissolved. It was made in accordance with the guidelines of Fusayama and the modification of Holland.[17] All these components were supplied by (Central Drug House (P) Ltd., India) except $NaH_2PO_4.2H_2O$, which was supplied by (BDH Chemicals Ltd., Poole, England). The magnetic stirrer was set at a temperature of 37°C and a speed of 40 rpm, and the components of AS were dissolved separately. After that, the specimens were stored in AS prepared at 37°C for seven days. After a period of seven days, the samples were

first eliminated from the storing means and then wiped with a cotton tissue until they became free from visible moisture.

Table 1: AS Compositions (in gm).

KCl	NaCl	$CaCl_2.2H_2O$	$NaH_2PO_4.2H_2O$	$Na_2S.9H_2O$	Urea
0.4	0.4	0.795	0.78	0.005	1

2.3 Characterisation of Prepared Composite Materials

The tensile test was achieved according to the standard (ASTM D638-87b). This inspection was done at room temperature using the universal tensile machine (Type LARYEE) with a 50 KN load capacity. The rate of strain (crosshead speed) was 2 mm/min, and the tensile load was exerted slowly till the sample fractured. The modulus of elasticity and tensile strength were obtained from this test. The flexural test was assessed according to ASTM D790-03 utilising a Three-Point Bend Test (width (b) ~13 mm, thickness (h) ~5 mm, and length ~160 mm) in universal testing equipment at a (5 mm/min) crosshead speed (strain rate), and the applied load was equal to 50 kN till the occurrence of the specimen breakage. The flexural modulus and flexural strength were obtained from the flexural test.

The test of hardness (Type Shore-D) was conducted on the PMMA before as well as after the reinforcing was supplemented, and the mean of five readings in every state was taken for obtaining higher accuracy outcomes. The test of hardness was achieved in accordance with the standard ASTM D2240 via the Dorumeter Hardness Test, and the measuring depressing time was equal to (15 sec). Each specimen was tested three times, and the average values were taken. The test of surface roughness was conducted by utilising the Surface Roughness Tester (TR 200) instrument, delivered with a sensor moving linearly alongside the measured length. Any specimen was investigated seven times on various area of each specimen at the same time, and the average value was taken.

3. RESULTS AND DISCUSSION

Figure 1 displays the influence of the GF and Y_2O_3 supplements upon the modulus of the elasticity of PMMA. It can be noted that the enhancement in the elasticity modulus with the supplement of both reinforcement types could be ascribed to the enhancement in the PMMA matrix stiffness owing to the decrease in its molecular movement as well as free volume. On the other hand,

the slight decrease was (9%). This may be owing to either the filler aggregation or the formation of voids during the procedure of moulding. Furthermore, the reason for such performance may be related to the weak physical bonds that accompanied the increase in the weight fraction. Also, this resulted in this performance may be from separated PMMA chains due to the increase of Y_2O_3, which in turn caused a decrease in the mechanical properties of the resulted composite. This result agrees with the previous results by Jarboo and Alsarraf, Mohammed et al., and Oleiwi et al.[13,18,19]

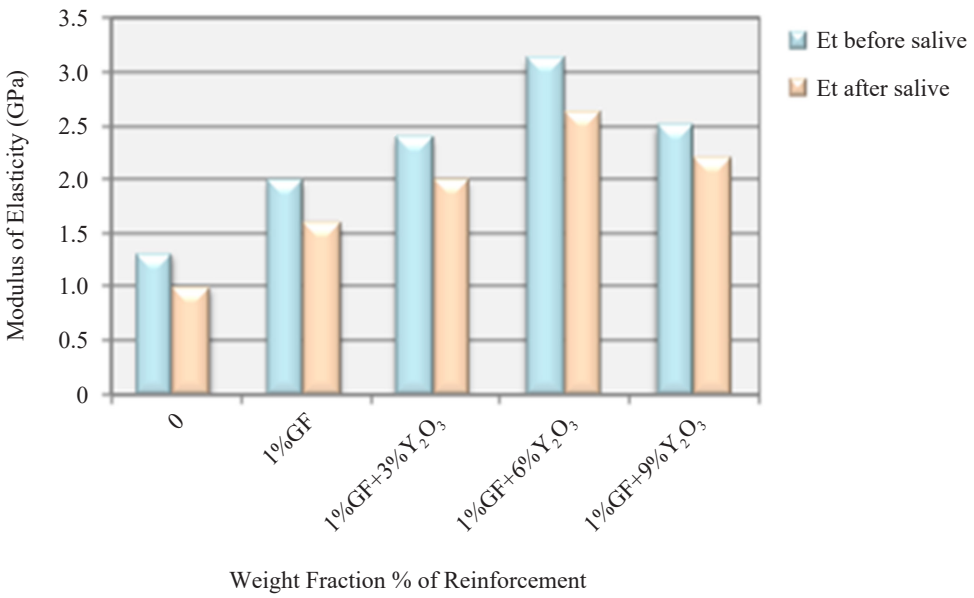

Figure 1: Modulus of elasticity results.

The same trend was observed for the ultimate tensile strength, as shown in Figure 2, which was enhanced after the addition of reinforcement materials due to the combination of particles with polymer resin. This improved compatibility between the base material and the reinforcing material also enhanced the ability of the sample polymeric composites to transfer the load from the base material to the strengthening material. These results agree with the previous results by Mohammed and Attalah.[20]

The highest modulus of elasticity and the ultimate tensile strength reached a value of (3.123 GPa) and (56.231 MPa), respectively, for (PMMA-6%Y_2O_3-1%GF).

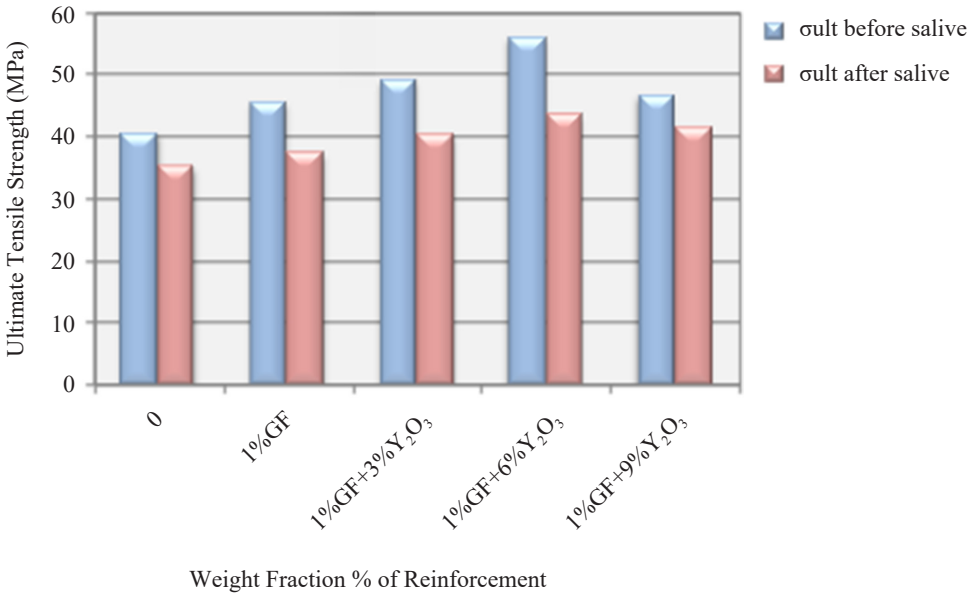

Figure 2: Ultimate tensile strength results.

The results of flexural strength are explained in Figure 3. It can be seen that the flexural strength is considerably augmented for the whole group in comparison with the control group. This result agrees with previous study by Mohammed et al.[18] The 1% GFs addition and the different ratios of Y_2O_3 caused different influences on the composite material's flexural strength. The flexural strength augmented slowly up to (6%Y_2O_3+1%GF) and then a decrease occurred to (9% Y_2O_3+1%GF) in comparison with the control group (0 wt%). The maximum recorded value of the flexural strength of the group that contains (6%Y_2O_3+1%GF) was 40.333 MPa compared to the control group's 29.667 MPa.

Additionally, as illustrated in Figure 4, the composites' flexural modulus exhibited the same behaviour. This result is consistent with previous studies.[22–25] Flexural characteristics of the resultant composite are influenced by interactions between the matrix of the composite and the added reinforcement. In a composite structure, the interfacial adhesion of reinforcement and matrix indicates how interfacial shear stress transfers from the reinforcement to the matrix.[26–27] The high contact area between reinforced fillers and PMMA resin in acrylates modified with GFs and Y_2O_3 led to increased load transfer and finally improved flexural properties.

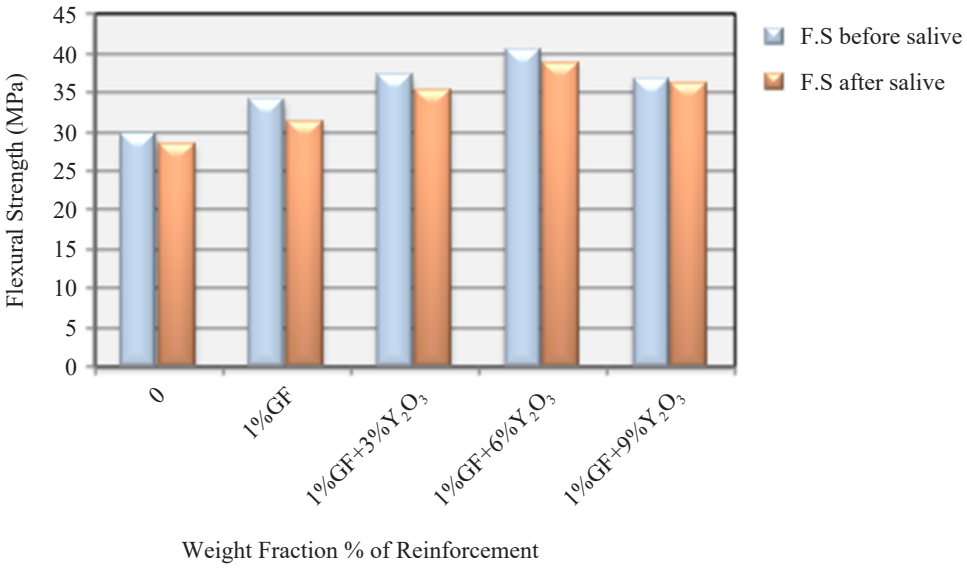

Figure 3: Flexural strength results.

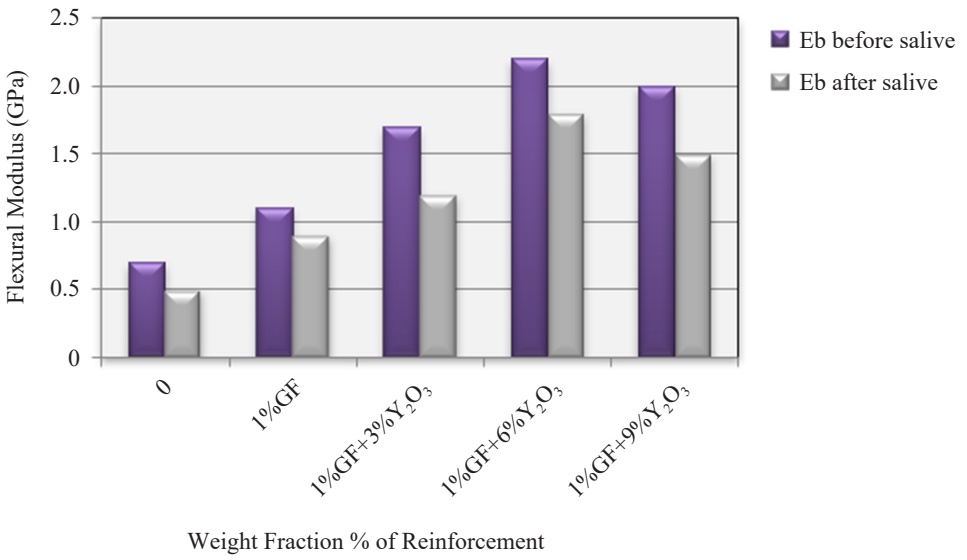

Figure 4: Flexural modulus results.

Figure 5 shows the relationship between hardness and strengthening materials' weight portion being supplemented to the PMMA resin. This figure depicts that the hardness raises with the rising weight portion and reaches its maximum amount at (9 wt.%Y_2O_3+1%GF), which is equal to 84. That's due to the increment of reinforcing; the composite gets harder in comparison with the polymer matrix. The reinforcements used have a higher elastic modulus value than the matrix (control PMMA). So, much more resistance was provided by these reinforcements to impede the indenter from penetrating the sample surface at that specific load, compared with that of the control PMMA sample. The obtained results of the present study are in good agreement with the findings reported by others who concluded that reinforcement of ceramics and fibres.[21]

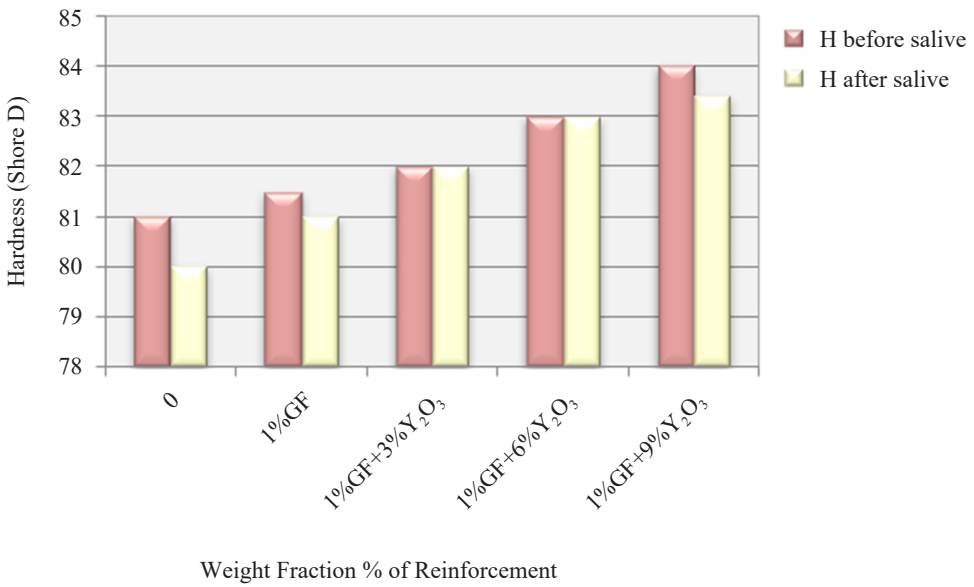

Figure 5: Hardness test results.

Figure 6 explains the effect of particles and fibres on the surface roughness of composites, and this figure indicates that the reinforcing leads to a clear increase in surface roughness. Also, it was found that the higher surface roughness was obtained with a sample containing 1%GF+6%Y_2O_3 and that it slightly decreased after that. The increase in surface roughness reached 2.78 μm for (1%GF+6%Y_2O_3) compared with the value of 2.012 μm for the control PMMA.

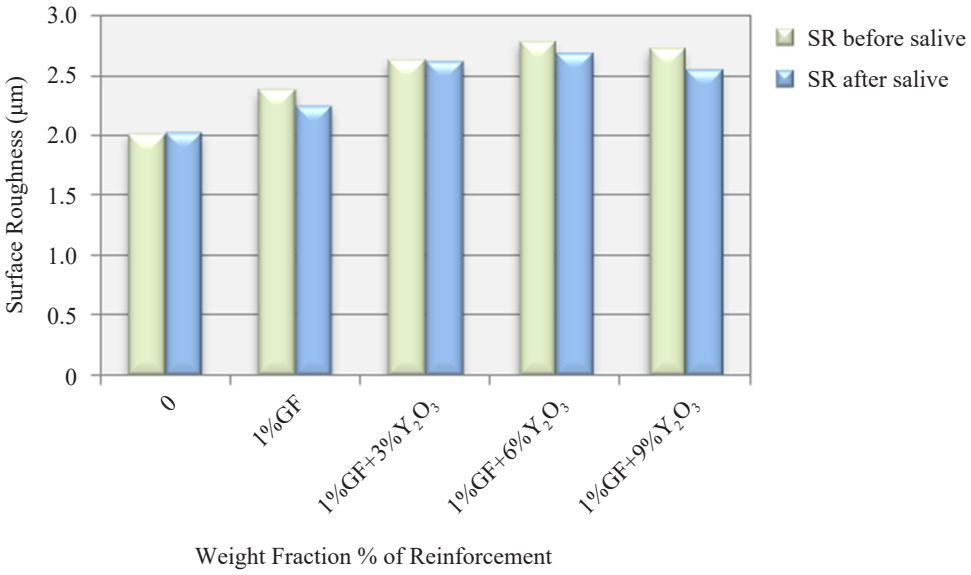

Figure 6: Surface roughness results.

Tensile, flexural, hardness and surface roughness are associated properties, and the mechanical properties tested usually determine the permanency of biomaterials within the oral cavity.[22] Within an oral cavity, such materials are subjected to endogenous matters, such as bacteria, polysaccharides, enzymes, proteins, etc., and exogenous matters throughout the consumption of food. Such matters create an intricate interaction and a mechanical action on the synthetic prosthesis, compromising its overhaul lifetime. Because of the wet condition, the presence of saliva reduces the overall mechanical properties.

So, in Figures 1 to 6, the whole mechanical properties of specimens decreased after immersion in the synthetic saliva. The explanation for this decrease in the properties is the plasticising influence of saliva. Bearing in mind that saliva may work as a plasticiser, succeeding as well as diffusion into polymer, increasing calming the chains of polymer and consequently reducing the mechanical behaviour of acrylic composites, and this result agrees with previous study.[28]

4. CONCLUSION

From the present study, the main conclusions are:

1. The addition of GF led to improvements in the tensile strength, modulus of elasticity, flexural bending, flexural strength, hardness and surface roughness of PMMA resin.
2. All the mechanical properties are enhanced with the increased weight fraction of Y_2O_3.
3. The specimens with 6%Y_2O_3 and 1% GF have the optimum properties.
4. Storing the specimen in the synthetic saliva led to reduction in all the mechanical properties.

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