Estimation of Some Properties of PMMA Matrix Reinforced with Yttrium Oxide and Glass Fiber for Dental Applications

Zinah N. Alabdali [a] *, Alaa A. Mohammed [b], Jawad K. Oleiwi [c]

Department of Materials Engineering, University of Technology-Iraq

[a,*] Zinah.alabdali@uotechnology.edu.iq, [b] alaa.a.mohammed@uotechnology.edu.iq, [c]130041@uotechnology.edu.iq

ABSTRACT

The aim of this study is to modify the performance of PMMA which is suitable for denture application. It is desirable for Polymethyl methacrylate (PMMA) to have high mechanical properties for dental applications like denture. The reinforced of PMMA with 1 wt.% glass fiber and different weight percentage of Y_2O_3 were estimated. Increase the mechanical and physical properties were found with increased the weight percentage of Y_2O_3. The maximum impact strength was obtained by using 6% Y_2O_3 with 1 wt.% glass fibers. The physical properties, which are included density and water absorption increased with increased the weight percentage of Y_2O_3 in PMMA. Furthermore, the improvement in impact strength was obtained at 6% Y_2O_3 was 45.48%. Finally, the SEM results show the homogenous distribution of Y_2O_3 in PMMA.

Keywords: - denture, polymethyl methacrylate, physical properties, impact strength, FTIR

تقييم بعض الخصائص لمادة الاساس البولي مثيل ميثااكرليت المقواة باليتريوم اوكسايد والياف الزجاج لتطبيقات الإسنان

الهدف الاساسي من الدراسة الحالية هي تحسين الاداء لمادة PMMA المناسب لتطبيق طقم الاسنان. من المفضل ان يمتلك البولي مثيل ميثااكرليت اعلى خصائص ميكانيكية لتطبيقات الاسنان مثل قاعدة طقم الاسنان. تم تقييم خصائص PMMA المقوى بإلياف زجاج بنسبة وزنية 1% ونسب وزنية مختلفة Y_2O_3. تم الحصول على اعلى مقاومة صدمة للنموذج الحاوي 6% Y_2O_3 مع 1% الياف زجاج. الخصائص الفيزيائية المتمثلة بالكثافة وامتصاصية الماء ازدادت مع زيادة النسبة الوزنية Y_2O_3 في PMMA . علاوة على ذلك , تم الحصول على تحسن في مقاومة الصدمة عند نسبة 6% Y_2O_3 كانت بمقدار 45.48%. واخيراً, اظهرت نتائج SEM توزيع متجانس لل Y_2O_3 في PMMA .

Keywords: PMMA, yttrium oxide, glass fiber, dental applications

INTODUCTION

Polymethyl methacrylate (PMMA) is a common acrylic resin used in different dental applications. PMMA was used in fabrication of denture because of some physical properties like dimensional stability, aesthetics, and bio-compatibility(S. T. J., S. M. F., A. Z., and J. M). PMMA is insufficient to fulfill all the requirements of the denture properties. The fracture of the denture is the important problems occurred during wearing as a result of the exposure to the load during the dynamic mastication (D. C. Jagger, A et al). In order to prevent fracture, adding additives like fiber, filler, and nanoparticles were added to enhance the properties of the denture (T. Bashi and L. Al-Nema). Yttrium oxide (Y_2O_3) is a thermodynamically stable metal oxide. Y_2O_3 has common characteristics of ceramics that are not found in metallic or organic materials. Y_2O_3 has high mechanical properties, high temperature stability, and chemical and erosion resistance (B. I. Khalil et al). The glass fibers are most widely used as a reinforcing material in different applications (A. J. Bonon et al). In general, for dental application, glass fibers reinforcement has better biomechanical properties, superior tension properties, and flexure features (M. Zhang and J. P. Matinlinna).

In some previous studies, Karci and et al were studied the effect of 3 wt.% and 5 wt.% nano titanium dioxides (n-TiO2) on the reduced flexural strength (M. Karci, N. Demir and S.Yazman) The mechanical characterization like compression strength was investigated for PMMA after adding different weight percentage of bamboo and siwak fibers. Increased the weight percentage of bamboo and siwak to PMMA increase the compression strength (J. K. Oleiwe et al). Asim and et al were improved the hardness and biological properties for PMMA matrix reinforced with two types of nanoparticles, which are involve zinc oxide (ZnO) and tricalcium phosphate (TCp) at weight (1,2,3 and 10) % separately (F.A. Asim et al). Other study was focused on evaluated water absorption and thermal conductivity of PMMA after adding different weight percentage of polymer fibers like polypropylene (PP). Increasing in the weight percentage of additives led to increase in the water absorption while decreased in thermal conductivity (H. Sharhan, Z. Rasheed, and J. Oleiwi). The tensile properties were calculated after adding different amounts of walnut and peanut shell powders. The tensile properties were increased at the 8 wt.% of additives (Z. M. Abdul Monem et al). Ibrahim and et al were produced a new denture composite material consist of PMMA matrix reinforced with nano aluminum oxide (Al_2O_3) at ratio (1, 3, 5 and 10) % and investigate the effect of reinforcement on mechanical and physical properties for resultant composite. In addition to analysis the morphology by SEM (R.A. Fouad et al).

The current work is focused on adding 1 wt.% of glass fibers and various wt.% Yttrium Oxide (Y_2O_3) to the Polymethyl Methacrylate (PMMA) and to estimate the mechanical and physical properties of the blend. The mechanical properties were calculated by used the Izod impact. The water absorption and density of the specimens were tested. Fourier Transform Infrared Spectroscopy (FTIR) was used to determine the chemical peak intensity. The Differential Scanning Calorimetry (DSC) was used to calculate the glass

transition temperature (T_g) and melting temperature (T_m). Scanning Electron Microscopy (SEM) used to show the embedded of glass fibers and Y_2O_3 in PMMA.

MATERIALS

The Polymethyl Methacrylate (PMMA) was used as a base acrylic resin and purchased from Spofa dental Company, Mowding LTD, UK. Yttrium Oxide (Y_2O_3, 99.95% pure, particles size ≤ 25 μm) and glass fibers were used as additives and purchased from Sigma-Aldrich, Germany. All the chemicals were used without further purification. Silicon mold of 80 mm x 10 mm was used to prepare the specimens for impact test. Also 10 x 10 mm^2 silicon mold was used to prepare specimens for water absorption and density test. FTIR, DSC, and SEM specimens were prepared by using 0.5 x 0.5 mm^2 silicon mold.

SAMPLE PREPARATION

The PMMA pure was prepared as a matrix according to the manufacturer's instructions which include a mix of 3 wt. % of powder with 1wt.% of liquid as a binder. Yttrium Oxide (Y_2O_3) was then added at different weight percentages as shown in (Table 1) to the PMMA blend. The additives of Y_2O_3 were added to the PMMA and blended via hand utilizing a wood spatula for 20 minutes to obtain a homogenous mixture. Half of the mixture was poured into the silicon mold as a lower layer and glass fibers were added as a middle layer at a constant ratio 1 wt.% then the other part of the mixture was continuously added as a top layer. The specimens were left in the mold for one day. After that the specimens were taken out from the mold, cleaned, and immersion in distill water for 48 hrs. The procedure above was done at room temperature 23±2 ℃. Three specimens for each ratio were prepared and tested. Figure (1) shows the test composite specimens prepared for this study.

CHARACTERIZATION

IZOD IMPACT

Izod impact test was used to measure the impact strength properties. Izod impact testing is suitable for composite materials, which are sensitive to high temperature and stress concentration (N. M. Z. Abidin et al). The specimens were prepared depend on the international standard No. (ISO-180). The specimen was fixed in vertical direction and the handle (tool steel) of the impact test was loaded toward the specimen by 5.5 Jole. This test was followed the (ISO-180).

WATER ABSORPTION AND DENSITY

The dry specimens were weighted by used a digital weight scale and then suspended by used wire in distilled water for 24 hrs. The wet specimens were extracted from the water and removed excess water from the surface by using clean cloth and weighted again in the same procedure. The water absorption was calculated by using (Eq.1) where W_1 stands for

dry specimens and W_2 for wet specimens. The specific gravity was calculated by using (Eq. 2) and then multiplied by the density of the distilled water, that is 0.9975 (g/cm^3) to obtain the total specimen density. W_D, weight of the dry specimens, W_i , weight of the suspended specimens in water, and the 0.02, which is the weight of the engaging wire as shown in (Eq.3)(D20 Committee) and (R. K. Durkan et al). All the procedure was depended on the ASTM standard (D-792) for density and ASTM standard D570 for water absorption.

$$\text{Water Absorption} = \frac{W_2 - W_1}{W_2} * 100 \quad (1)$$

$$\text{Specific Gravity (S. G.)} = \frac{W_D}{W_D - W_i + 0.02} \quad (2)$$

$$\text{Density} = \text{Specific Gravity} \times 0.02 \quad (3)$$

FOURIER TRANSFORM INFRARED SPECTROSCOPY (FTIR)

ATR (attenuated total reflectance), Tensor 27 type, Bruker, Germany was used to measure the FTIR spectra. The wavenumber ranges from 400 to the 4000 cm^{-1} was used with 4 cm^{-1} resolution and accumulation 2. OriginPro™ 2021 software was used to plot the spectra after correcting the baseline, smoothing and curve fitting all the data (Z. N. Alabdali et al). This characterization was done according to ASTM E1252.

DIFFERENTIAL SCANNING CALORIMETRY (DSC)

The glass transition temperature (T_g) of the specimens was measured using DSC 214 Polyma, Netzsch Gerätebau, Selb, Germany. Melting temperature (T_m) also was measured in the same way. Aluminum crucible was used to hold the specimens inside the chamber of the DSC. The heating rate is 10 ℃ min^{-1} and the maximum temperature is 250 ℃ and fixed for 10 min and then cooled until it reached to the room temperature.

SCANNING ELECTRON MICROSCOPY (SEM)

SEM Inspect F50, FEI Company was used for surface characterization as shown in figure (2). The specimens were coated with a 10 nm thickness of gold to obtain conductive specimens.

RESULTS AND DISCUSSION

IZOD IMPACT

Figure (3) illustrate the results of Izod impact test, which is included impact strength. The addition of Y_2O_3 with 1wt.% glass fibers to PMMA significantly increases the impact strength compared with PMMA pure (T. Kanie et al). The impact strength of PMMA was increased with additives because of high mechanical properties of Y_2O_3 and glass fibers.

The mechanical properties of Y_2O_3 and glass fibers are higher than the PMMA pure (Ö. Karacaer et al). Addition of 1 wt. % glass fibers with 9 wt.% of Y_2O_3 decreased the impact strength of the PMMA, which belonged to the increase the brittle properties of specimens when increase the weight percentage of additives.

WATER ABSORPTION AND DENSITY

Fig4a and 4b) illustrates the effect of addition Y_2O_3 with glass in PMMA on water absorption and density. Figure (4a) shows increased the weight percentage of the Y_2O_3 with glass in PMMA increased the percentage of water absorption, which is related to the molecules of water are capable for penetrating among the polymer chains. Also, the affinity of additives to the absorption of water. Figb) shows the increased in density with increased the weight percentage of Y_2O_3 with glass in PMMA. These results are related to the higher density of additives than the density of PMMA pure. Furthermore, increased the weight percentage of additives, which is higher density means decreased the weight percentage of PMMA pure, which is the lower density (V. M. Miettinen et al).

FOURIER TRANSFORM INFRARED SPECTROSCOPY (FTIR)

Figure 5a) was illustrating the results of FTIR spectra of PMMA pure. The two strong peaks of methyl group CH_3 shows around (~2800 cm^{-1}) due to stretching or vibration. A peak at (~ 1700 cm-1) which is related to the C=O, while around (~ 1400 cm-1) related to C-H group. Furthermore, C-O bands appear at range (~1000-1400 cm^{-1}). Figure b) Shows the effect of glass and Y_2O_3 on the methyl group. There is no effect of addition of 1 wt.% glass to PMMA on the intensity of the methyl bonds, while the addition of different weight percentage of Y_2O_3 decrease the intensity of the peaks and shift to the left. Increase the weight percentage of Y_2O_3 increase the C-O peaks as shown in Figure c). The maximum intensity of C-O peak was obtained with 6 wt.% Y_2O_3 with 1 wt.% fiber glass as shown in Figure (5c).There are no other new peaks shown, which is mean no chemical interaction occurred between the Y_2O_3 and PMMA (Z. N. Alabdali et al).

DIFFERENTIAL SCANNING CALORIMETRY (DSC)

The Table 2 shows the results of the glass transition and melting temperature. The addition of Y_2O_3 with 1 wt.% glass in PMMA effected on the value of Tg and T_m. The addition of 1 wt.% glass decrease the melting temperature compared with melting temperature of PMMA pure. The addition of different weight percentage of Y_2O_3 decrease the melting temperature compared with PMMA with 1 wt.% glass. This related to many reasons, one of the most common reasons is different in melting temperature of PMMA, glass and Y_2O_3. The melting temperature of glass or Y_2O_3 higher than melting temperature of PMMA. The addition of 1 wt.% glass increase the T_g. While the addition of different weight percentage of Y_2O_3 decreased the T_g compared with the T_g of PMMA pure. The addition of additives to PMMA decrease the mobility of the chain in the matrix.

SCANNING ELECTRON MICROSCOPY (SEM)

Figure (6) shows the SEM images for different specimens. Figure (6a) shows the image of PMMA pure at fracture surface area, which indicated the homogeneous morphology and unique area after fracture. Figure b) shows the glass fibers orientation while Figure (6c) shows the morphology of PMMA with 1 wt.% of glass fibers. The images show the better relation between the glass and PMMA, which is indicate better bonds adhesion between glass fibers with PMMA. Figure (6d) shows the PMMA with 1 wt.% glass fibers and 3 wt.% of Y_2O_3, which is shows a homogenous distribution in PMMA and covered the glass fibers.

Conclusion:

According to above results, the mechanical properties like impact strength increased from (8.04 to 11.62 KJ/m^2). The physical properties like density were ranged from (1.09–1.13 gm/cm^3), while water absorption ranged from (1.45-1.94%). Fourier Transform Infrared Spectroscopy (FTIR) spectra shows the intensity of CH_3 peaks decreased after added 3wt.% or 9 wt.%Y_2O_3 with 1 wt.% glass fibers to PMMA. 6 wt.% Y_2O_3 with 1 wt.% glass fibers increased the intensity of CH_3 peaks which is related to the physical bonds between the additives and PMMA. Melting temperature decreased with increase the weight percentage of Y_2O_3 with 1 wt.% glass fibers. In conclusion, the addition of 6wt.% Y2O3 was gives the best properties. The future study will focus evaluate more properties such as fatigue and antibacterial properties.

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Table 1: Composition of each specimen in weight percentage wt.%

PMMA wt.%	Glass fibers wt.%	Y_2O_3 wt.%
100 %	-	-
99 %	1%	-
96%	1%	3%
93%	1%	6%
90%	1%	9%

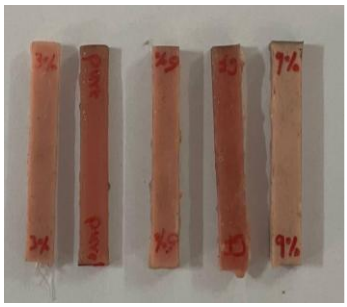


Figure (1): Impact Test Composite Specimens.

Figure (2): SEM machine

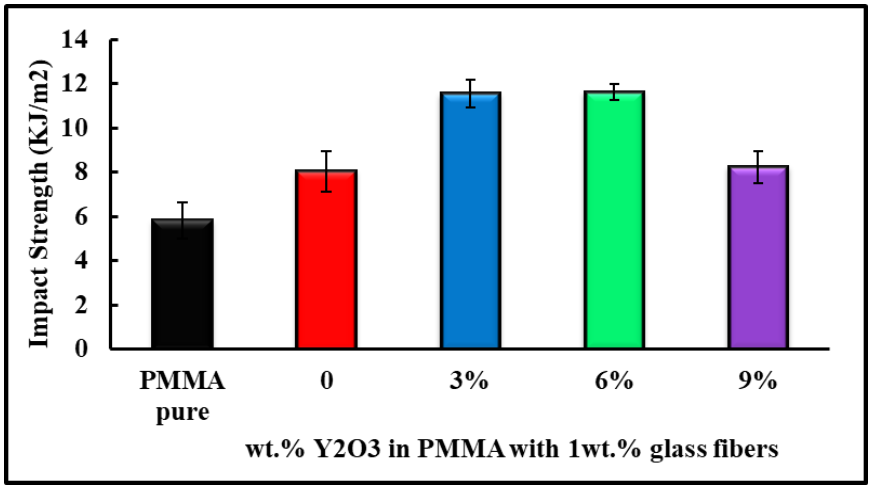


Figure (3): The relation between impact strength and wt.% Y_2O_3 in PMMA with 1wt.% glass fibers

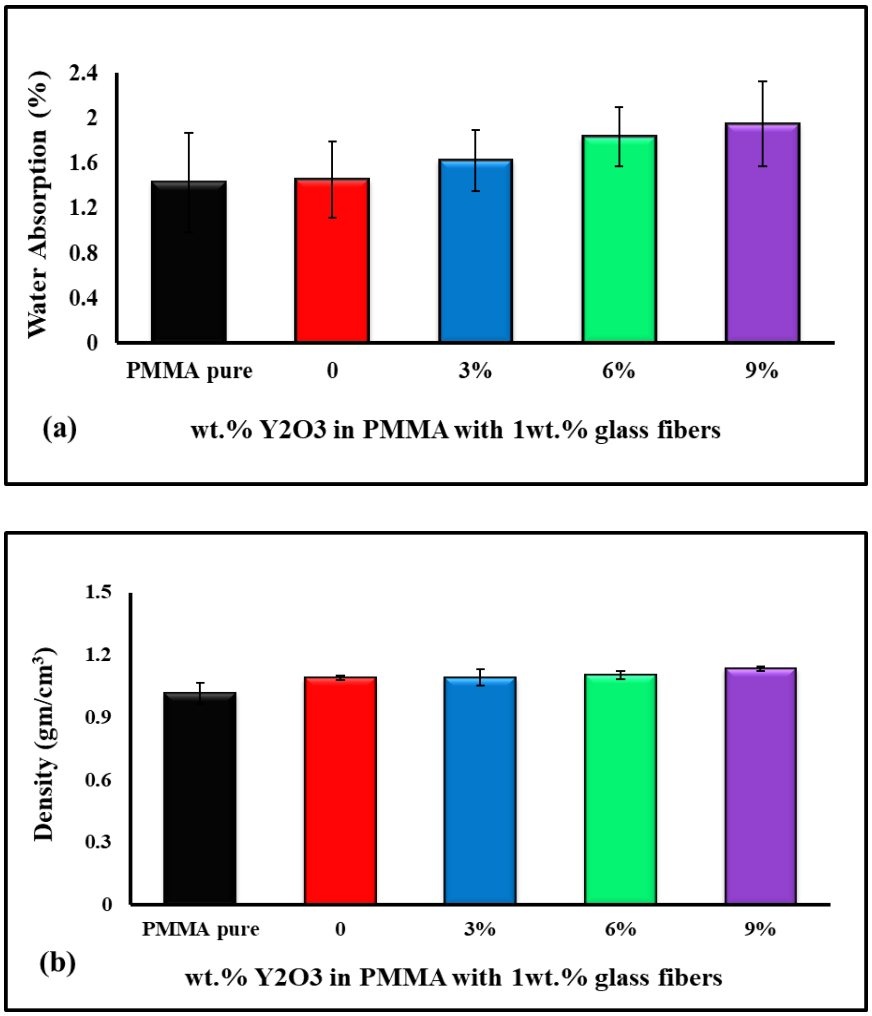
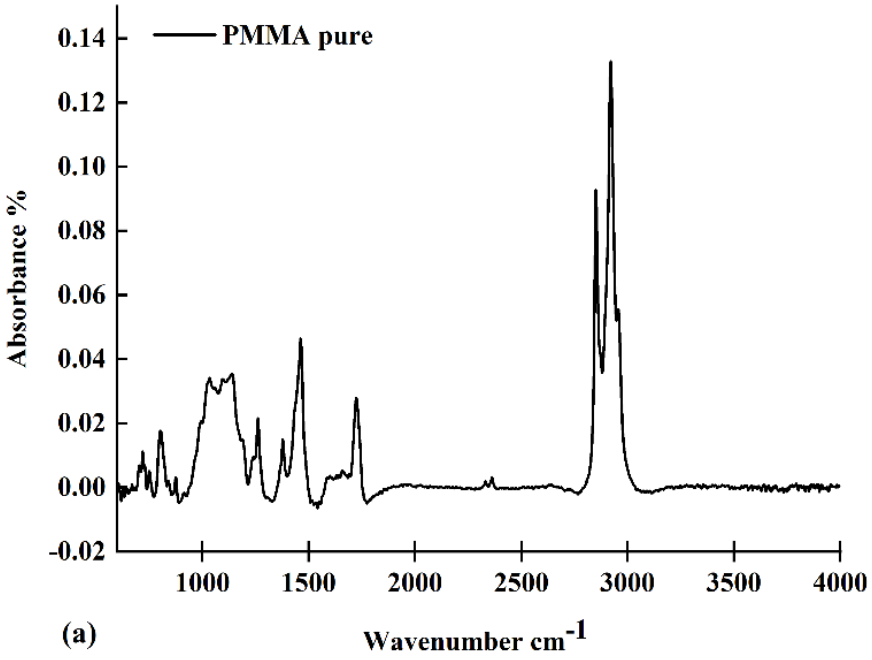
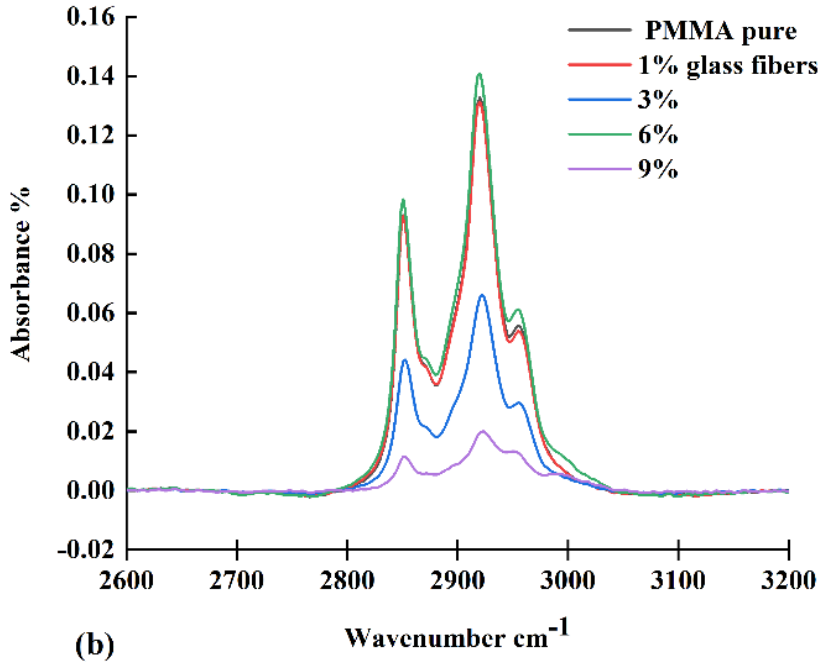


Figure (4): (a) The relation between water absorption and wt.% Y_2O_3 in PMMA with 1 wt.% glass fibers (b) The relation between density and wt.% Y_2O_3 in PMMA with 1 wt.% glass fibers


PMMA pure
Absorbance %
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
1000
1500
2000
2500
3000
3500
4000
Wavenumber cm-1
(a)


PMMA pure
1% glass fibers
3%
6%
9%
Absorbance %
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
2600
2700
2800
2900
3000
3100
3200
Wavenumber cm-1
(b)

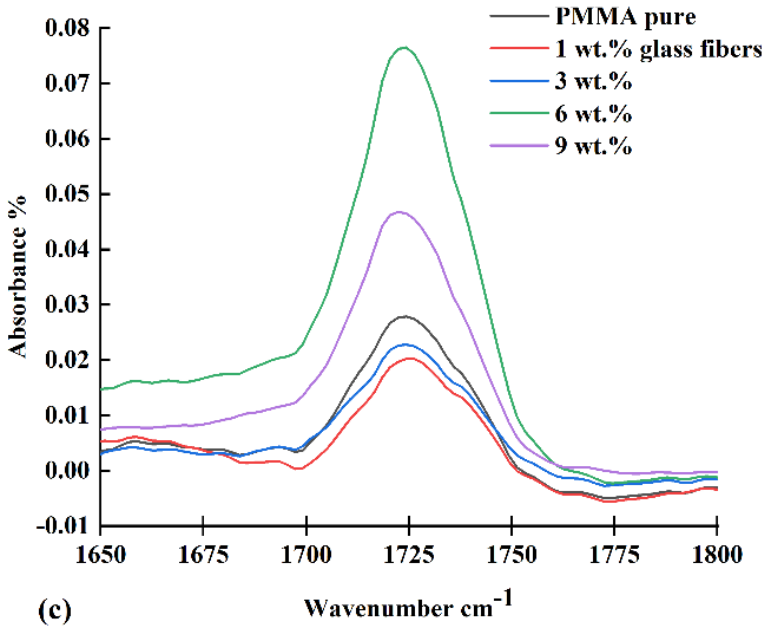


Figure (5): (a) The spectra of PMMA pure, (b) the variation in intensity of CH_3 bonds, (c) the different in intensity of C=O bonds

Table 2: The DSC results show the T_g and T_m for the specimens.

Wt.% Y_2O_3 in PMMA with 1 wt.% glass fibers	T_g (°C)	T_m (°C)
PMMA pure	119.053	160.259
0 wt.% Y_2O_3	119.841	160.088
3 wt.%Y_2O_3	111.542	160.343
6 wt.%Y_2O_3	111.755	160.304
9 wt.%Y_2O_3	111.405	159.957

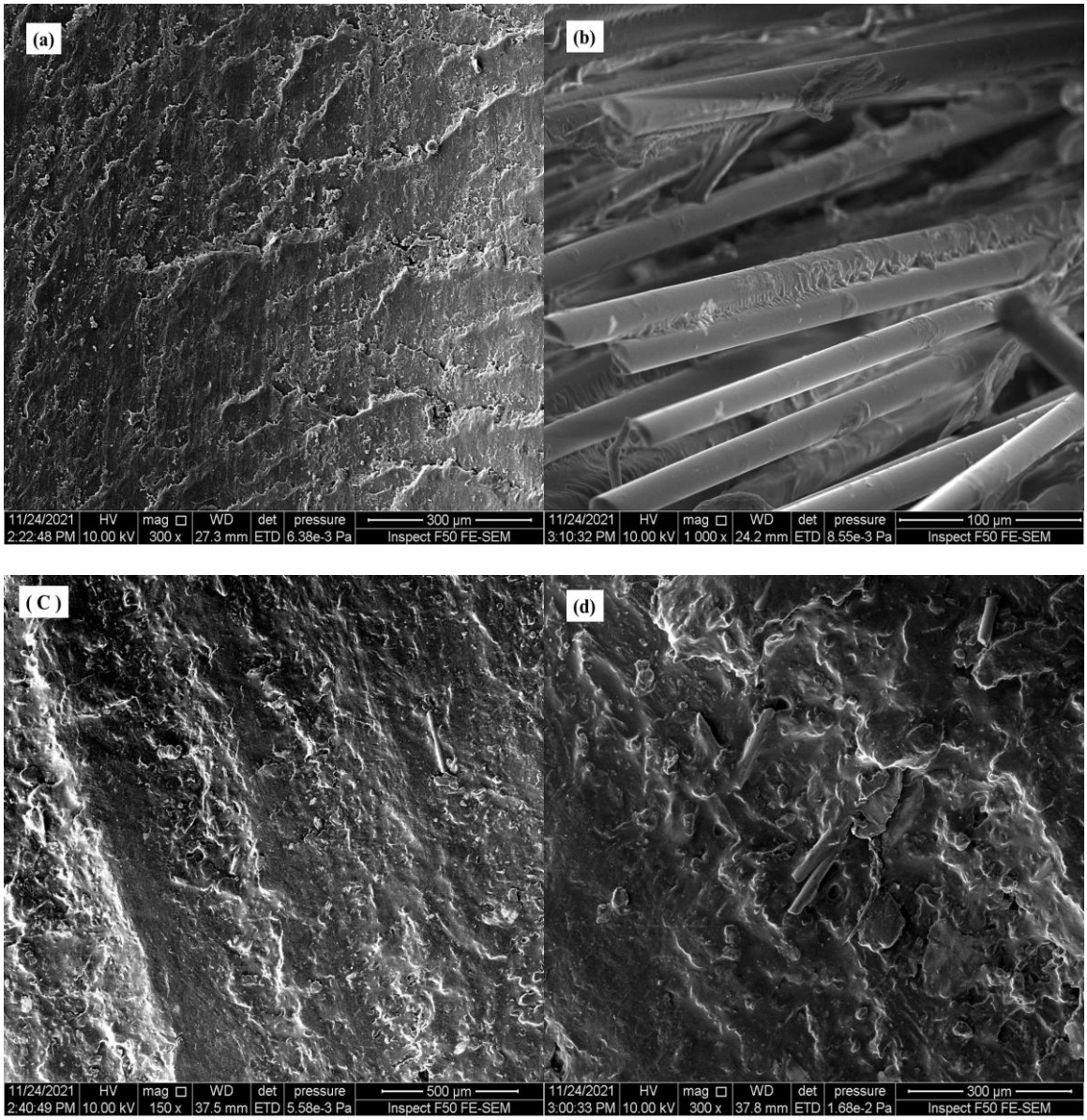


Figure (6): SEM images: (a) PMMA pure, (b) glass fibers orientation, (c) 1 wt.% glass fibers distribution in PMMA, (d) 1 wt.% glass fibers and 3 wt.% Y_2O_3 in PMMA

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