Comparative study of some mechanical properties of nanocomposites based on the polymer’s blends used for dentures base applications

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Abstract
Recently, high mechanical and physical properties of PMMA material have encouraged many researchers to work in the denture’s applications. However, it is a weak material in terms of fatigue loads and impact strength. In the present research, two types of polymer blend nanocomposite samples were manufactured by utilizing a hand lay-up method used to produce the complete or partial dentures base. Polymer blends containing (poly methyl methacrylate resin and 2% natural rubber (NR)) were used as matrix; it was strengthened by two kinds of natural powder in the nanometer size of clove powder and pomegranate peels powder (PPP) individually, with a chosen weight fraction percent of (0.0, 0.1, 0.3, 0.5 and 0.7% wt). The results manifested appreciably the advanced values of flexural strength, flexural modulus, maximum shear stress, fracture toughness and impact strength for both kinds of hybrid composites specimens compared to matrix material (PMMA: 2%NR).

Composite specimens of polymer blend (PMMA: 2%NR) matrix reinforced by (PPP) elucidated the highest values for these properties as compared with their counterpart of nanocomposites, which reinforced by clove nanoparticles. The highest values for the flexural strength and maximum shear stress reached to 144 MPa and 3 MPa, respectively at 0.5% ratio of PPP, whereas the highest values of flexural modulus, impact strength and fracture toughness reached to 3.3 GPa, 10 KJ m⁻² and 5.74 MPa.m⁰.⁵, respectively at 0.7% ratio of PPP for polymer blend nanocomposite (PMMA: 2%NR: 0.7% PPP). Depending on these results, it can be concluded that the addition of natural fillings in a nanometer size of pomegranate peels or clove powders individually to the polymer blend (PMMA: 2% NR) material is one of the promising materials that can be used to improve the mechanical properties, especially the fracture strength for the complete or partial dentures base.

1. Introduction
PMMA is one of the most important artificial materials used for fabricating partial or complete denture base. The utilization of PMMA in this field is due to its higher mechanical properties, but it possesses low mechanical strength, so it is necessary to develop the properties of PMMA by using a reinforced method, such as strength by particles or fibers [1]. There are different methods utilized to modify the properties of PMMA in such type of application. There were many efforts to reinforce the polymers using different procedures. Previously, the definition of nano strength led to great advantages in strengthening the mechanical properties of PMMA denture base materials [2]. The effect of glass fiber, as a reinforcing material, on the flexural strength and fracture resistance of acrylic resin was investigated, and the result gave an indication about the possibility to enhance the flexural strength of the heat cured PMMA [3]. The application of PMMA denture base does not only need a high mechanical functioning, but also it looks for a good biosafety and biocompatibility, while some inorganic substances led to cause agitation or even harm to the gingival tissue and oral cavity mucosa [4]. Studies revealed
that the hydroxyapatite nano filler was utilized in the dental field as an active biocompatible powder to reinforce the PMMA matrix [5]. The use of nano zirconia in PMMA for denture base has been reported to advance the transverse strength according to the nano size and a good distribution [6]. Among these methods is reinforcing the PMMA resin by modifying with fiber and utilized graft co-polymerization with high-impact strength resins [7]. Regarding the influence of the particles size and content ratio of the silica (SiO₂) ceramic particles on the mechanical properties of PMMA polymer, the results illustrated that the modulus elasticity, tensile strength and bending modulus of PMMA composites were improved by increasing the addition of SiO₂. Also, the resulted values evidenced that the impact energy and fracture toughness of PMMA composites were decreased by raising the content of SiO₂ particles. Zirconia reinforced acrylic resin significantly increased its transverse strength of PMMA denture resin [8]. Nanotechnology has invaded the prosthetics field for the enhancement purposes of medicine and material. Properties of strengthen PMMA resin by nanoparticles depend on the type, shape, size and the concentration of particles [9]. Another study demonstrated that the flexural and impact properties of PMMA composites reinforced with rice husk (RH) and bamboo powder in an individual form increased with increasing the fillers content for both types of rice husk and bamboo powder in composite materials [10]. The mechanical properties of PMMA composites were strengthened by different kinds of the natural fillers, such as pomegranate peels PPP and seed powder of dates Ajwa SDP on the flexural properties; fracture toughness and impact strength values were studied. The result demonstrated a considerable development in these properties for both groups of bio composites; moreover, all biocomposite samples strengthened by the PPP nano fillers revealed the highest properties [11].

From a recent study in the field of the use of PMMA composites in bio applications, Gopalakrishnan, et al prepared PMMA composites consisting of PMMA reinforced with (0, 1, 2, 5 and 10) weight percentage of AgNPs for converting a bio-inert polymer into a biocompatible, biofilm resistant, anti-microbial, strong polymer with superior modulus and abrasion resistance [12]. Another study about PMMA nanocomposites exhibited the effect of the addition of ZnO NPs with different weight percentages to a PMMA material prepared by using the ex-site compression moulding technique on the antimicrobial and mechanical behavior. The result indicated that the addition of 1 wt% of ZnO nanoparticles led to enhance some of the physical and mechanical properties, also the antimicrobial of the polymer PMMA without changes in the structural and morphological properties [13]. The effect of concentration of AgNP on the transport behavior and flexural properties for PMMA composites was investigated by Gopalakrishnan, et al, the result elucidated that the addition of AgNPs decreased the salivary sorption and water sorption. As well, it is effectively held up the crack propagation, fracture and disclosed the smaller cracks at the concentrations up to 5 wt% [14].

The aim of this research is a comparative study of some mechanical properties between two groups of nanocomposites based on the polymer’s blends (PMMA: 2%NR), which are reinforced by two types of natural nano powders, pomegranate peels (PPP) and clove added individually, to be used for dentures base applications.

2. Materials and method

2.1. Materials

The composite prosthetic dentures specimens consist of polymeric materials, which are poly methyl methacrylate (PMMA), natural rubber (NR) and reinforcement materials as natural powders in nanometer size. The matrix of materials included polymeric blends (PMMA (heat curing): 2%NR) as a control sample. PMMA material was used as fluid resin matrix, type (Spofa Dental Company, Czech Republic). The blending material was the natural rubber (NR). Two different kinds of nanometer sized natural powders, including clove powder (CP) and pomegranate peels powder (PPP) shown in figures 1(a) and (b), respectively were used in this study as strengthening fillers with a weight fraction of (0.0, 0.1, 0.3, 0.5 and 0.7% wt) and with an average diameter of 75.18 and 88.93 nm, respectively.

2.2. Preparation of specimens

The PMMA denture materials in this work consist of PMMA base material, which contains two parts of polymer powder and monomer liquid (methyl methacrylate, MMA). The standard mixing ratio for a heat curing polymerized acrylic resin is usually volumetric ratio about (3:1); that means (3) of polymer powder (PMMA) and (1) monomer liquid (MMA) according to the company instructions. In this work, to prepare polymer blends as well as the polymer blend nano composites samples, initially, the liquid (MMA) part of acrylic resin was mixed with the NR material at 2% ratio until the mixture was becoming perfectly homogeneous, after that, a powder of PMMA was added to this mixture with a continuous mixing process, and then the mixture was poured into a metallic mold prepared for this purpose. The mold was pressed by using a hydraulic compressor with a pressure of about 2.5 bars to get a smooth surface and to avoid the gases vapor from the entry into PMMA during the curing. The curing process for acrylic was performed under the conditions of 70 °C and 2.5 bar for 30 min.
according to the company instructions. Then, the temperature was raised to the (100 °C) and stayed for one hour. And then, the process of cooling the mold began inside the curing device in order to remove the residual monomer. The samples were removed from the metallic mold, with very smooth surfaces. The final heat treatment at 55 °C for 3 h was done to remove the residual stresses found within the samples. The same steps were followed when preparing the composites materials samples.

3. Physical and mechanical tests

3.1. The atomic force microscopy
Atomic force microscopy (AFM) is used to study the materials by scanning over the surface with a very sharp tip. By AFM, one can study and resolve the size of particles, the structure and details of the surface down to the atomic level as well as investigate the granularity and roughness. In the present work, AFM was used for testing the samples to check the average diameter of nanoparticle and its distribution and for testing the surface roughness of samples, the microscope instrument was manufactured in Germany by (Bruker Optics Company), model (TENSOR 27). This instrument is capable of performing contact mode, tapping mode, lateral force microscopy and scanning tunneling microscopy. The (AFM) technique is usually used to get a real three-dimensional image with x, y, z axis of the surface. The atomic force microscope traced out the surface with better than nanometer resolution.

3.2. Fourier transform infrared (FTIR) spectrum
Fourier transformation Infrared (FTIR) spectrum was used to get the specific information about the chemical bonds and molecular structure of the polymer samples. The (FTIR) spectrum test was accomplished due to (ASTM E1252) [15]. FTIR devise, model (TENSOR 27) manufactured in Germany by (Bruker Optics Company), was utilized. Infrared spectrum was used within a range of 400–4000 cm\(^{-1}\).

3.3. Mechanical tests
The flexural and impact tests were performed in order to evaluate the fracture toughness properties for all the prepared polymer blends composite samples.

3.3.1. Flexural test
Flexural strength was measured from three-point test, according to ASTM D 790-78 [16] at the room temperature (23 ± 5 °C) and atmospheric pressure, this test was carried out with a crosshead speed of 5 mm min\(^{-1}\) until the failure of the samples occurred.

3.3.2. Impact strength test
Impact strength is an important property for polymeric materials, which have different behaviors, depending on the type of polymeric material, manufacturing conditions, shape of the sample and test temperature. It was conducted by the ISO 179 [17] with Charpy type impact testing instrument (N 43-1, New York, USA). All tests were accomplished at the room temperature, for control samples and experimental group's samples.
3.4. Morphology test

Morphology test was done to analyze the fracture surface morphology of the polymeric blend and nanocomposites samples by using Scanning Electron Microscope (SEM), this instrument is made by (FEI-Netherlands), model (INSPECT S50). The sample used in the testing was cut into small pieces to fit into the device, and to achieve a good electrical conductivity, all samples were first sputtered with gold from the surface along the edge. Secondary electron images were then recorded, with a working voltage at range (10–25 KV).

4. Result and discussion

4.1. Results of the AFM test

4.1.1. Particle size analysis

In order to make sure that the powders prepared from the natural materials are within the nano scale, they were subjected to the size analysis by using atomic force microscopy (AFM) - scanning probe microscope (CSPM) to check the average diameter of clove powder (CP) and pomegranate peels powder (PPP) and their distribution. Figure 2 depicts the results of the particle size analysis for clove powder as received by AFM test, where the granularity cumulative distribution is within the ranges of (≤50% Diameter:70.00 nm) and (≤90% Diameter:90.00 nm), and the average diameter is 75.18 nm that is shown in the table in figure 2(a). The granularity cumulative distribution chart for clove powder is depicted in figure 2(b), a three-dimensional (XYZ) AFM picture for clove powder was taken by AFM (figure 2(c)), which confirmed that the prepared nanoparticle of clove powder was within the nano size.

Figure 2. AFM test of clove powder nanoparticles with average diameter 75.18 nm. (a): a table showing the particle size analysis of clove powder as received by AFM test, (b): granularity cumulative distribution chart of clove powder, and (c): a three-dimensional (XYZ) AFM picture for clove powder.
4.1.2. Surface roughness test results

Figure 4 illustrates the morphology of surfaces roughness, which was tested by AFM technique, from this figure; it was observed that there are different constructions in the surface structure morphology of the samples depending on the roughness of the surface, which varies according to the nature of their components. Where, figure 4(a) represents the morphology of the surfaces of neat PMMA, and figure 4(b) represents the morphology of the surfaces of polymeric blend (PMMA: 2%NR). It is evident from the construction of the surface that the surface structure of neat PMMA sample in figure 4(a) is smoother with surface roughness 4.69 nm as compared to the blended samples. The morphology of the surfaces of nanocomposite’s specimens reinforced by clove powder nanoparticles with the weight fraction ratios (0.3%, 0.5%, and 0.7%) is shown in figures 4(c)–(e), where figures 4(f)–(h) represents the nanocomposites that reinforced by pomegranate peel powder with particle size (88.93 nm). From these constructions of surface, it was noticed that the structure of the surfaces of the nanocomposites that reinforced by pomegranate peel powder has a lower surface roughness as compared with their counterparts’ samples of nanocomposites reinforced by clove powder nanoparticles having particle size (75.18 nm) with polymer blend (PMMA: 2%NR) and neat PMMA. This result may be attributed to the nature of pomegranate peel powder and clove powder and on the inter–particle interactions between these nanoparticles and the constituents of polymer blend, and this depends mainly on the nanoparticles surface chemistry, shape, aspect ratio and dimensionality, the inter–particle distance and the polydispersity.

4.2. Results of the FTIR test

This test was utilized for the full characterization of the heat curing PMMA, binary polymer blends (PMMA: 2% natural rubber) and specimens as a function of the addition of natural powders of clove powder (CP) and
pomegranate peels powder (PPP). The frequency ranges used in this test was 400–4000 cm$^{-1}$. The infrared spectrum for the neat PMMA in figure 5(a) is quite similar to that reported in literature [18, 19]. In this spectrum, the absorption peaks at 2991.51 cm$^{-1}$ and 2950.40 cm$^{-1}$ correspond to the C–H asymmetric stretching in CH$_3$ and CH$_2$, respectively. The vibrational band at 2849.97 cm$^{-1}$ is according to the C–H

| Microscopy photos for Surface roughness by AFM | Specimen components and Surface roughness value (nm) | Microscopy photos for Surface roughness by AFM |
|-----------------------------------------------|----------------------------------------------------|-----------------------------------------------|
| ![Image](a)                                   | Neat PMMA (4.69 nm)                                | ![Image](b)                                   |
| ![Image](c)                                   | (PMMA: 2%NR) (9.3 nm)                              | ![Image](d)                                   |
| ![Image](e)                                   | (PMMA: 2%NR): 0.3CP (8.83 nm)                      | ![Image](f)                                   |
| ![Image](g)                                   | (PMMA: 2%NR): 0.5%CP (7.49 nm)                     | ![Image](h)                                   |
| ![Image](i)                                   | (PMMA: 2%NR): 0.7%CP (7.58 nm)                     |                                               |
| ![Image](j)                                   | (PMMA: 2%NR): 0.3%PPP (2.37 nm)                    |                                               |
| ![Image](k)                                   | (PMMA: 2%NR): 0.5%PPP (1.67 nm)                    |                                               |
| ![Image](l)                                   | (PMMA: 2%NR): 0.7%PPP (1.51 nm)                    |                                               |

Figure 4. The surface roughness image in three-dimensional (XYZ) with the values of the surface roughness. (a) for neat PMMA, (b): for polymer blend (PMMA: 2%NR), (c)–(e) For nanocomposites ((PMMA: 2%NR): X%CP), and (f)–(h): For nanocomposites ((PMMA: 2%NR): X%PPP).
symmetric stretching in CH₃. The characteristic band for the neat PMMA was observed at 1722.54 cm⁻¹, which corresponds to the C=O stretching band. The vibrations mode according to the deformation modes of CH₃ groups appeared at 1434.50 cm⁻¹ and at 1386.33 cm⁻¹. Medium bands at 1239.49 cm⁻¹ match to the C–O stretching modes. The band at 1189.65 cm⁻¹ corresponds to the CH₃ wagging, owing to the C–C stretching appeared at 985.98 cm⁻¹ and 964.96 cm⁻¹. The peaks at 911.30 cm⁻¹ and 840.40 cm⁻¹ are assigned to the CH₂ rocking, and the peaks at 808.09 cm⁻¹ and 749.44 cm⁻¹ are due to the CH₂ rocking in and out of plane bending, respectively. These results are in an excellent agreement with other results of workers [19, 20].

The infrared spectrum of the blend specimen similar to the all vibration bands of the neat PMMA presented in figure 5(a) was offered in the FTIR test of polymeric blend specimen (PMMA: 2% NR). Figure 5(b) displays the FTIR spectrum of the binary polymer blends (PMMA: 2% NR). The characteristic band for PMMA was noted at 1721.54 cm⁻¹, which matched to the C=O stretching band. The vibrations mode according to the deformation modes of the CH₃ groups are seemed at 1434.77 cm⁻¹ and at 1387.04 cm⁻¹. Medium bands at 1239.93 cm⁻¹ correspond to the C–O stretching modes. The band at 1140.69 cm⁻¹ is due to the CH₃ twisting.

Figures 6(a) and (b) evinces the FTIR spectra of the clove powder and the pomegranate peel powder, respectively. These spectra confirmed the complex nature for the peels and proved the presence of materials in a wide variety of compounds. It has been reported by studies that the pomegranate peels contain different natural compounds with a biological nature [21]. The infrared spectrum shown in figure 6(a) for the prepared clove powder nanoparticles is quite similar to that obtained in [22]. It can be observed from this spectrum that the peak at 3442.94 cm⁻¹ of the O–H stretching band has reinforced the existence of alcohols compounds and...
carboxylic acids. The stretching band of C=C alkyne group was recognized at bandwidth 2951.09 cm\(^{-1}\). The sharp peak at 1732.08 cm\(^{-1}\) is a characteristic to the carbonyl group C=O, which leads to the presence of aldehydes, ketones and carboxylic acids, and the sharp peak at 1616.35 cm\(^{-1}\) showed the existence of unsaturated compounds (alkenes). The band at 1516.05 cm\(^{-1}\) for the CH\(_2\) bending verified the presence of cellulose. The infrared spectrum depicted in figure 6\(b\) for the prepared pomegranate peel powder nanoparticles is also quite similar to that reported in [22]. From this spectrum, it can be noticed that the band at 3460.3 cm\(^{-1}\) of the O–H stretching band has reinforced the presence of alcohols compounds and carboxylic acids. The stretching band of C=C alkyne group was detected at bandwidth 2920.23 cm\(^{-1}\). The sharp peak at 1735.93 cm\(^{-1}\) is attributed to the carbonyl group C=O, which leads to the presence of aldehydes, ketones and carboxylic acids, and the sharp peak at 1618.28 cm\(^{-1}\) indicates the presence of the unsaturated compounds (alkenes). The band at 1350.17 cm\(^{-1}\) for the CH\(_2\) bending corroborated the presence of cellulose. Also, for the clove powder, it can be seen from the spectrum that the band at 3442.94 cm\(^{-1}\) of the O–H stretching band has reinforced the existence of the alcohols compounds and carboxylic acids. The stretching band of the C=C alkyne group was recognized at bandwidth 2951.09 cm\(^{-1}\). The sharp peak at 1732.08 cm\(^{-1}\) is a characteristic to the carbonyl group C=O, which leads to the presence of aldehydes, ketones and carboxylic acids, and the sharp peak at 1616.35 cm\(^{-1}\) revealed the existence of the unsaturated compounds (alkenes). The band at 1516.05 cm\(^{-1}\) for CH\(_2\) bending verified the presence of cellulose.

Figures 7 and 8 view the FTIR spectra for the two groups of polymeric blends nanocomposites ((PMMA: 2% NR): X%CP) and ((PMMA: 2%NR): X%PPP), respectively as a function of CP and PPP content (0.0, 0.1, 0.3, 0.5 and 0.7%) which added individually. These spectra are quite similar to the FTIR spectrum of the neat PMMA control sample (figure 5\(a\)) and polymer blend (PMMA: 2%NR) (figure 5\(b\)). On the other hand, no any other new peaks were appeared, or any aberration in the positions of peaks that attributed to the characteristic bands was noted in the spectra of these nanocomposites with the addition of the nanoparticles of CP or PPP. These results manifested the occurrence of the physical bonds between the components of nanocomposites and the
absence from any chemical reactions or cross linking that may occur as a result of the mixing process of these nanocomposites [23].

4.3. Results of the flexural test

The effect of adding the natural nanoparticle filler from the clove powder (CP) and the pomegranate peels powder (PPP) individually to the binary polymer blend (PMMA: 2% NR) on the flexural strength, flexural modulus, and maximum shear stress for the nanocomposites is shown in figures 9–11, respectively. From these figures, it can be noted that there is a gradual increase of the flexural strength, flexural modulus and maximum shear stress with the extra increase of the weight fraction of PPP and CP nanoparticles content in the nanocomposites as compared to the control sample of the polymer blend (PMMA: 2% NR); this is owing to the good compatibility between the constituents of matrix materials and the natural reinforcing nano fillers [24]. On the other hand, the nanocomposites samples, which were reinforced by PPP nanoparticles, have higher flexural properties as compared to their counterparts of the nanocomposites sample that reinforced by CP nanoparticles, this result is in a good agreement with the other worker results [25]. These results can be attributed to the fact that the physical bonding strength associated with the good compatibility between the nanoparticle fillers (PPP and CP) and the components
Figure 8. FTIR spectra, where (a): for neat PMMA, (b): for polymer blend (PMMA: 2%NR), and (c)-(f) for nanocomposites ((PMMA: 2%NR): X%PPP) as a function of nanoparticle pomegranate peels powder content in composite.

Figure 9. Flexural strength for PMMA nanocomposite specimens as a function of weight fraction content for nanoparticles (CP and PPP) in composites.
of the polymeric matrix material (PMMA: 2% NR) has a considerable effect on the reduction of the free volume in the microstructure of the polymeric nanocomposites. This restricts the molecular motion of the polymeric chains, which leads to improve the stiffness of nanocomposites, reduces the plastic deformation, and thus increases the flexural properties of polymeric nanocomposites [26]. Moreover, it was noticed from these figures that the highest percentage increase of the flexural strength reached to 48.5% at 0.5%wt ratio of PPP content in the composites materials, whereas the highest percentage increase of the flexural modulus reached to 23.6% at 0.7%wt ratio of PPP content in nanocomposites. This result is related to the ability of the natural nanoparticles to avoid the propagation of cracks inside the polymeric matrix due to the reinforcing mechanism in addition to the good linking between the constituents of the blend materials and the natural nano fillers, this leads to an increase in the flexural strength, flexural modulus and shear stress properties for the prepared nanocomposites [26].

4.4. Results of the impact strength and fracture toughness
The impact strength value is the most important property because it gives an indication about the measure of a given material’s toughness. Impact strength of the composite samples is controlled by two factors: the first one is the ability of the strengthen materials to prevent the crack propagation by absorbing the energy, and the second one is the poor bonding between strengthen filler and matrix, which cause micro spaces and result in crack propagation [27]. Figures 12 and 13 demonstrate the effect of adding the natural filler from the clove powder nanoparticles and the pomegranate peels powder nanoparticles to the polymer blend (PMMA: 2%NR) on the impact strength and fracture toughness of nanocomposites, respectively. These figures also show the impact strength and the fracture toughness increased with the increase of the weight fraction of CP or PPP content in nanocomposites as compared to the polymer blend (PMMA: 2%NR) as control reached to 25% and 19%, respectively at a 0.7% ratio of PPP content in the nanocomposites ((PMMA: 2% NR): x% PPP). The reason behind this behavior maybe depends on that the impact test is a measure of the material’s toughness. So, the obtained results may be concerned with the typical distribution of the natural particles within the binary polymer blend (PMMA: 2%NR), and a good interfacial bonding.
between them leads to a considerable increase in the energy absorbing capacity of the bio nanocomposite specimens and that increases the fracture toughness of a nanocomposites materials \[^{28, 29}\]. The highest values of the impact strength and the fracture toughness reached to 10 KJ/m\(^2\) and 5.74 MPa.m\(^{1/2}\), respectively for the composite specimens \((\text{PMMA: 2\%NR}: 0.7\% \text{PPP})\), whereas these values for the composite specimens \((\text{PMMA: 2\%NR}: 0.5\% \text{CP})\) reached to 8.33 KJ/m\(^2\) and 4.55 MPa.m\(^{1/2}\), respectively.

### 4.5. Morphological analysis

The morphology test is dependent on many parameters, such as the quality of the blend, blending conditions, the viscosity of the polymers, the compositions of blend, the concentration of the reinforcing materials in composite, and the wettability between their components \[^{30}\]. In order to link the mechanical properties of the prepared polymer blend and its bio nanocomposite with their the microstructure morphology, the scanning electron microscopy (SEM) was used at magnification (X2000). The photographic image of the fracture surface morphology for neat PMMA material is revealed in figure 14(a). From this photographic image, a homogeneous structural morphology was observed, and there was no any new phase or separated phase dominating in this structure morphology, except the appearance of some microscopic pores, which were referred to by red arrows. Moreover, for the fracture surface morphology of the polymer blend sample (PMMA: 2\%NR), figure 14(b) depicts a dense and a homogeneous structural morphology free from microscopic pores, shows a smoother fracture surface, and indicates to the better interfacial adhesion between PMMA resin and natural rubber. This is due to the fact that the addition of the natural rubber to the PMMA material leads to reduce the viscosity of the polymer blend during the preparation of the blend and thus facilitates the flow process of the molten polymer blend during its freezing, resulting in the formation of the homogenous structure free of microscopic pores. Furthermore, figures 13(a) and (b) views the fracture surface morphology for the optimal samples of bio nanocomposites (PMMA: 2\%NR: 0.5\%CP) and ((PMMA: 2\%NR): 0.7\%PPP), respectively. These structural morphologies appear as co-continuous morphology, where there is no any
new phase or separated phases that are prevailing in the structural morphology for both types of bio nanocomposite, these structural morphologies are similar to the other workers findings [31, 32]. As well, the morphology from these photographic images elucidated no occurrence of any agglomerations for nanoparticles, which were randomly distributed within the structure of the polymer blend matrix, with a good distribution of both types of nanoparticles within the nanocomposite material. Where, the most nanoparticles were embedded into the polymeric material matrix which acted as an integral part of the polymer blends structure indicating to a good interfacial adhesion among the all constituents of the composite materials. And, this indicated to a perfect compatibility between the constituents of the polymer blend and the reinforcement nanoparticles (CP and PPP), and this leads to enhance the mechanical properties according to that obtained by other literature [33].

5. Conclusions

From the results of the present work, the following conclusions can be drawn:

1. The hybrid nanocomposites material ((PMMA: 2%NR): x% PPP) gained higher values of mechanical properties, as compared to ((PMMA: 2%NR): x% CP).
2. The mechanical properties of the polymer blend improved with the addition of the natural powder of pomegranate peels or close to it.

3. The maximum value of the flexural strength and maximum shear stress occurred at a 0.5% ratio of PPP content in the composite based on (PMMA: 2% NR), and the maximum values of impact strength, fracture toughness and flexural modulus took place at a 0.7% ratio of PPP content in nanocomposites.

4. The highest value of flexural strength, flexural modulus, maximum shear stress, impact strength and fracture toughness for the bio composite specimens with matrix (PMMA: 2% NR) are 144 MPa, 3.3 GPa, 3 MPa, 10 KJ m\(^{-2}\) and 5.74 MPam\(^{1/2}\), respectively.

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