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Analysis of Wear, Tensile and Thermal Properties of Poly Methyl Methacrylate Filled with Licorice Particle and Pomegranate Peels

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K E Y W O R D S

Poly Methyl Methacrylate

Wear, Tensile and Thermal tests

A B S T R A C T

In the present work, analysis of wear behavior, tensile and thermal properties have been done for two sets Poly Methyl Methacrylate samples which is reinforced through licorice particles and pomegranate peels particles. Wear rate resistance is evaluated based on Taguchi's experimental design L9 (MINITAB 18) under the three factors: weight fraction of fillers (1%, 2%, 3%, 4% and 5% wt.) sliding time (5, 8 and 11 min) and load applied (10, 15and 20N) using a pin-on-disk device. Results display that the samples (Poly Methyl Methacrylate +5% licorice particles and 5% pomegranate peels particles) show the best resistance wear of (0.045×10^{-6} and 0.10×10^{-6}) respectively. Signal to noise (S/N) results showed that 5% weight fraction (licorice particles and pomegranate particles with PMMA), 11 minutes (sliding time) and 15N (applied load) give the best resistance wear. Statistical analysis of tensile and thermal tests, exhibit that the best mean value of the tensile strength, modulus of elasticity, thermal conductivity, and thermal diffusivity are (±73 MPa, ±70 MPa, ±4.800 GPa, ±4.300 GPa, ±.5600 W/m k, ±.5400 W/m k, ±.3800 mm^2/sec, ±.2800 mm^2/sec) respectively, of the samples (PMMA+5% licorice particles and 5% pomegranate peel particles). While that the best mean value of the elongation at break (±3.600%, ±3.500%) respectively, of the samples (PMMA + 1% licorice particles and 1% pomegranate peel particles). The results showed that the addition of licorice and pomegranate particles to poly methyl methacrylate resin has improved the properties of wear, tensile and thermal properties.

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1. Introduction

Poly Methyl Methacrylate polymer resin is widely used as a denture base material due to its desirable properties include durability, lightweight, low cost, and chemical stability. Despite these properties, the denture base does have less mechanical properties, such as intolerance to the high forces that occur inside the mouth due to the repeated masticatory consequently leads to the fall of the denture base [1]. Thus, Poly Methyl Methacrylate resins must be strengthened by utilizing various materials to develop these properties. Wear of denture base is a progressive loss of material due to the act of rubbing. Many factors can reduce or increase the wear resistance, for example, the interfacial bond between the support materials, the size of the particles, the chemical composition of the filler material and the conditions of wear [2]. Natural materials are materials have two main sources (a) residual plant waste, (b) agricultural production such as sisal, coconut residue, pomegranate peel residue, cinnamon [3], and are widely used with polymers to form composites that can be used in various applications due to light-weight and density, non-toxic materials, high application performance and available in nature [4]. There are several studies that are examining the effect of natural particles on the physical and mechanical properties of the polymer bio-composites. Hanan A.R [5], studied the mechanical properties of the PMMA reinforced with (3%, 5% and 7% wt.) siwak particles. The results indicated that adding (5% wt. siwak particles to PMMA) improves the values of tensile strength, elongation, pressure strength and surface roughness, while adding (3% wt. siwak particles to PMMA) improves the values of impact strength. R. Karthick. et al. [6], evaluates the wear behavior and hardness of the PMMA strengthened by (2% to 20% wt.) nano-seashell. The samples (PMMA- 4%, 6%, and 8%wt. nano-seashell) give the better wear resistance and hardness when compared with the other weight fraction of nano sea shells. Emre et al. [7], in this study evaluating the wear, impact, hardness and compression properties for the PMMA reinforced by (1%, 3%, and 5% keratin, bone ash and hydroxylapatite). The wear test was estimated under the two variables: load (47 and 87 N) and sliding time (3 and 6 min). It is observed from the results the samples (PMMA -5% wt. bone ash) have the best values of impact strength and hardness, while the samples (PMMA -3% wt. bone ash) has the best values of compression. The samples (PMMA- 3%, 5% wt. bone ash and 5% wt. keratin) have the best wear resistance. M. Vinosh et al. [8], tensile, hardness and wear rate of three samples (pure PMMA), (PMMA - 3% silica) and (PMMA-3% polycarbonate) were studied in this work. From the results, notice that the maximum tensile value was present in the samples (PMMA-3% silica) and (PMMA-3% polycarbonate), also the maximum elongation value was present in the samples (pure PMMA) and (PMMA- 3% Silica). The samples (PMMA-3% polycarbonate) and (PMMA-3% silica) give the best properties of the hardness and wear resistance. Ahmed et al, [9 and 10] studied a statistical analysis of some mechanical properties using the OriginLab program for PMMA samples - 2%, 4%, 6% and 8% by weight with cinnamon and orange peel powder. The results exhibit that adding (8% wt. cinnamon and 8% wt. orange peel powder to the PMMA) improved the tensile strength, modulus elasticity, flexural strength, and flexural modulus when compared with pure PMMA. The addition of (2% wt. cinnamon, 2% wt. orange peel powder to PMMA) improved the elongation at break, also the addition of (6% wt. cinnamon and 6% wt. orange peel powder to PMMA) improved the impact strength. The main objective of this study is to evaluate the wear, tensile and thermal tests of the polymeric biocomposites manufactured from (PMMA - licorice and pomegranate peels) that can be used in a dental base. Estimate the effect of factors (weight fraction of fillers, sliding time, and load applied) on wear test by using Taguchi's experimental design (L9). The statistical analysis and ANOVA comparison (Tukey test) by (SigmaPlot 14) for the tensile and thermal tests to determine the best weight fraction of licorice and pomegranate peels powder.

1. Materials

I. Poly methyl methacrylate

Use of Poly Methyl Methacrylate polymer resin (Vertex™ Castavaria) to prepare the denture base samples. Table 1 exhibits some mechanical and physical properties of PMMA as obtaining from Vertex – Dental Company.

Table 1: Mechanical and physical properties of Poly Methyl Methacrylate.

Bending	Young modulus	Impact	Solubility	Density
79 MPa	1.64 GPa	8.3 KJ/m^2	109 $\mu g/mm^3$	1.1 g/cm^3

II. Licorice Particles

Licorice is an extract from the glabra plant that contains glycerol acid, it was used as a filler material with PMMA in this work. Figure 1 offers steps that are taken to obtain licorice particles. Figure 2 shows the granular size of licorice molecules after milling for 4 hours which are examined using (MASTERSIZER 2000), where the average size of licorice particles was (52 µm). Figure 3 shows the chemical analysis of licorice particles using the (XRF) technique.

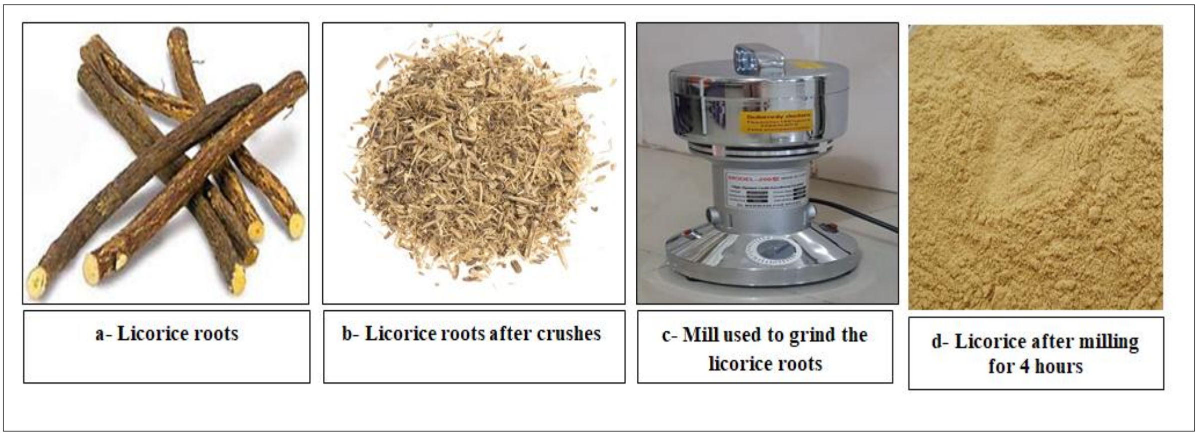


Figure 1: The steps used to obtain licorice particle.

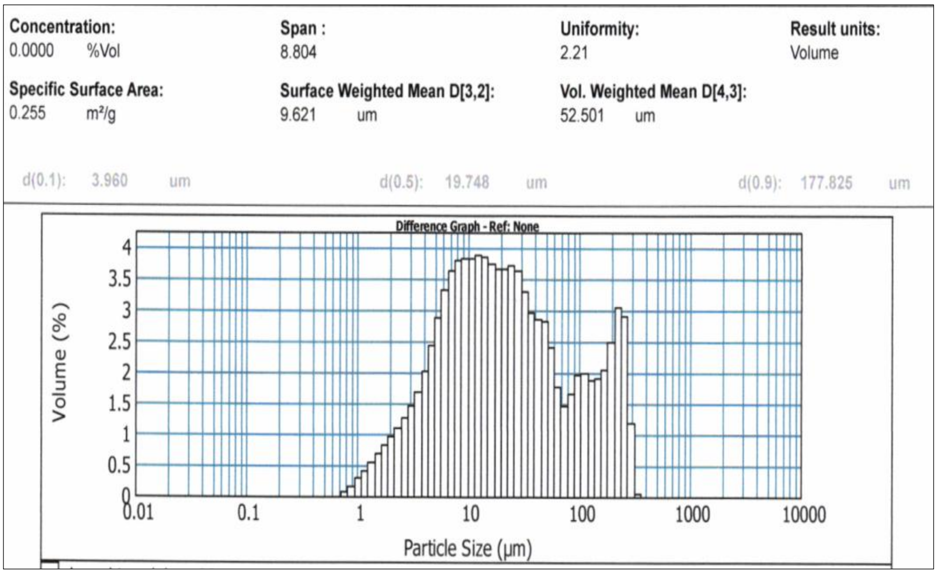


Figure 2: Average granular size of the licorice particle.

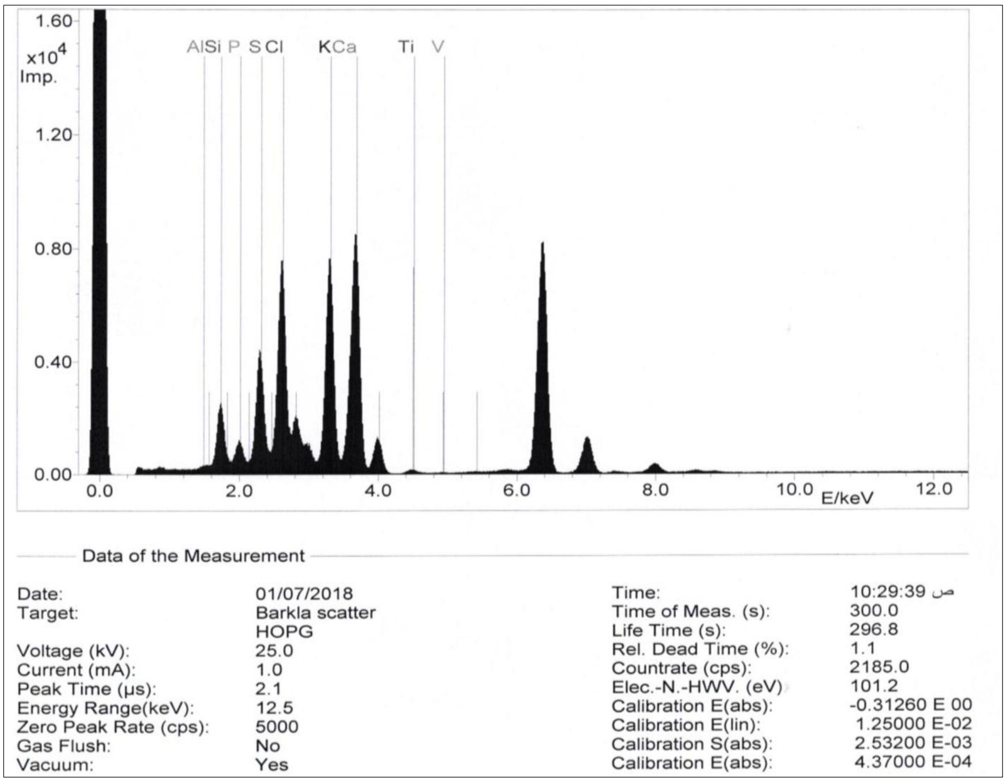


Figure 3: Chemical analysis of the licorice particle.

III. Pomegranate peels

The pomegranate peels leftover from the production of the juice can be recycled and used in medical and engineering fields. Pomegranate peels were used as fillers with PMMA in this work. Figure 4 offers the steps that are taken to obtain pomegranate peels particles. The granular size of the pomegranate peels after milling for 4 hours, which are examined using (MASTERSIZER 2000) was (54µm) and as shown in Figure 5. The chemical analysis of pomegranate particles performed using the XRF technique illustrates in Figure 6.

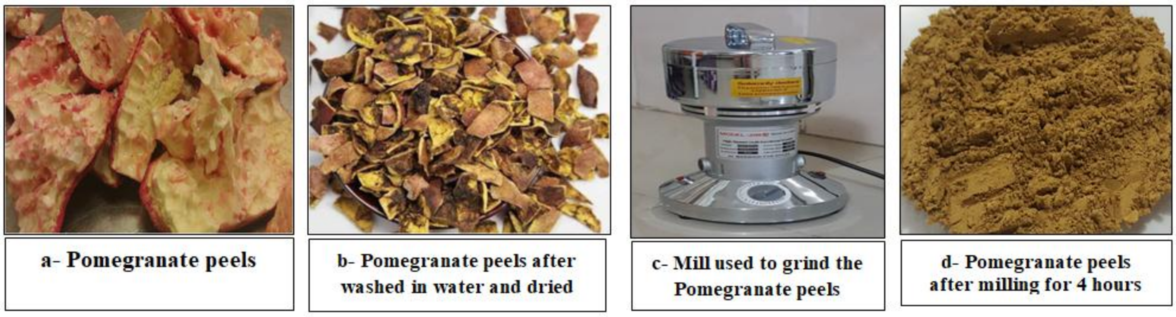


Figure 4: The steps used to obtain pomegranate peels.

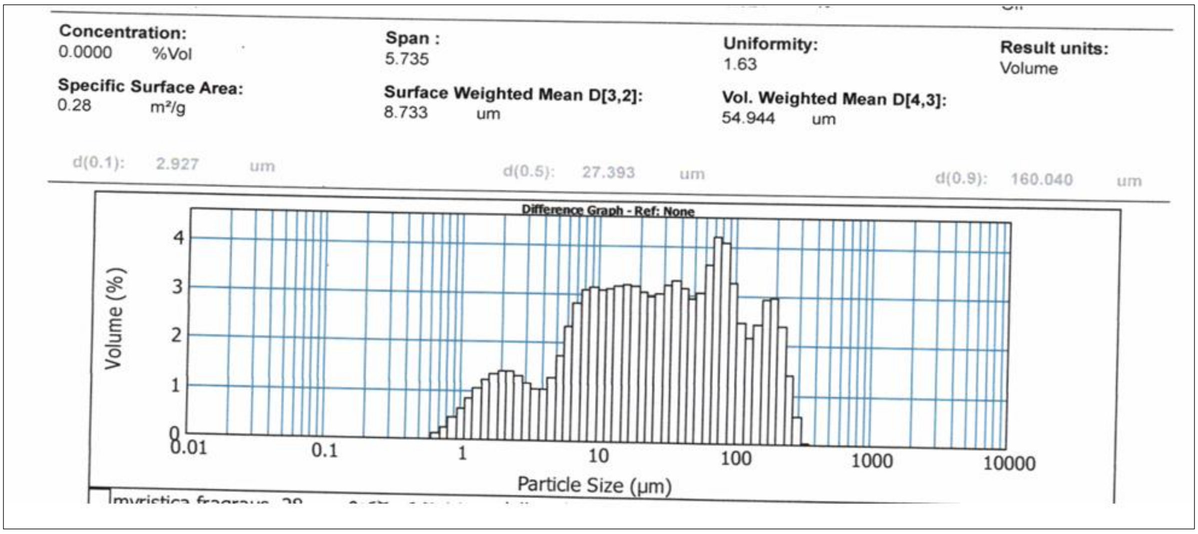


Figure 5: Average granular size of the pomegranate peel.

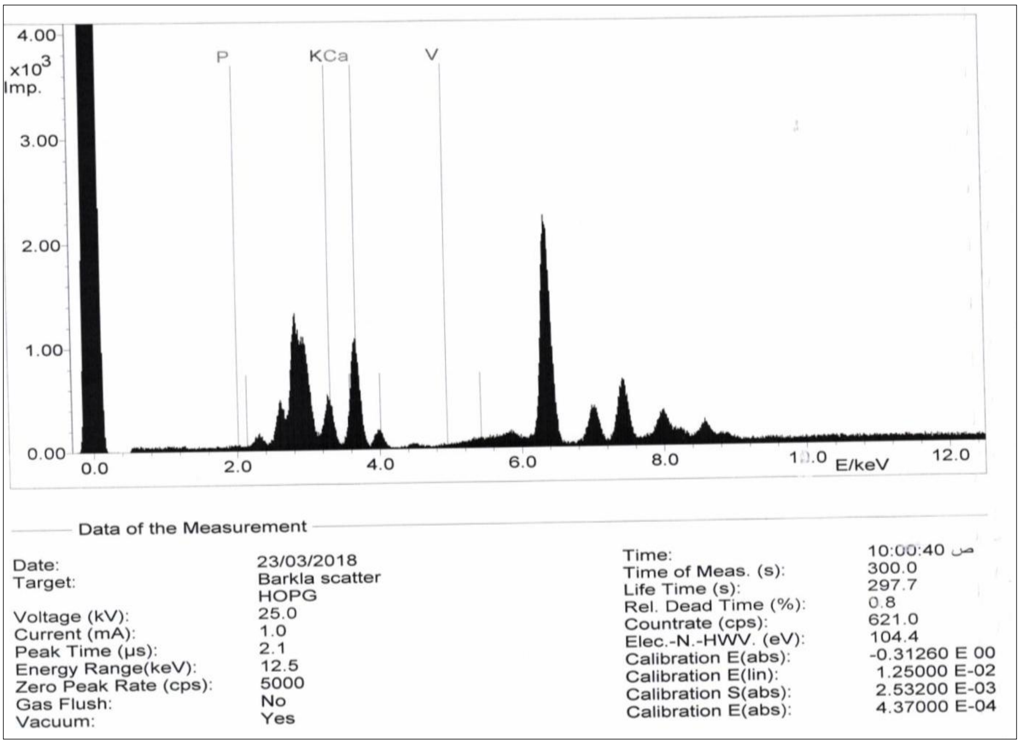


Figure 6: Chemical analysis of the pomegranate peels particle.

2. Prepare Samples

Composite sample plates are prepared by using the hand lay-up molding method from (1%, 2%, 3%, 4%, 5% wt.) of licorice particles and pomegranate peel particles are added as filler material to PMMA resin. The dimensions of the mold used in the casting process were (22 x 22 x 0.4 cm^3). To prepare the pure samples without any added fillers, mixed (19 gm) of the powder polymer, and (1.9) of the liquid monomer depending on the size of the mold used in preparing samples, it is recommended to pour the powder respectively into the liquid monomer. The samples strengthened with licorice particles and pomegranate peels particles are prepared by mixing the specific percentage of the filler particles with the polymer powder and gradually adding the mixture to the specific percentage of the liquid monomer and then pouring it in the middle of the prepared mold. Leave the mixture in the mold for 30 minutes at room temperature from the start of the mixing process as a working time to increase the viscosity of the mixture. The samples are removed from the mold and placed in the oven at a temperature of 50 ºC for 20 minutes to remove any remaining stresses in the samples and increase the bonding between the support materials and the polymer [11 and 12]. The samples are cut at least 3 samples per test and for each reinforcement. Details of the composition of the samples are exhibited in Table 2.

Table 2: Details composition of the samples (Poly methyl methacrylate filled with licorice particle and pomegranate peels particle).

Samples	Composition of the samples
P	PMMA
PL1	PMMA +1% Li
PL2	PMMA+2% Li
PL3	PMMA+3% Li
PL4	PMMA+4% Li
PL5	PMMA+5% Li
PP1	PMMA+1% Po.
PP2	PMMA+2% Po.
PP3	PMMA+3% Po.
PP4	PMMA+4% Po.
PP5	PMMA+5% Po.

3. TEST PROPERTIES

I. Wear Test

Figure 7 exhibits the shape of the device utilized to measure the wear behavior rate, which is of type pin on the disk. The dimensions of the samples were (12 mm) diameter and (25mm) length according to ASTM- G99-04 [13]. The original weight of the samples was recorded before starting experiments using accuracy electronic scales. Wear experiments evaluated based on Taguchi's experimental design L9 (MINITAB 18) and under the influence of three factors: weight fraction of fillers (1%, 2%, 3%, 4% and 5% wt. licorice particle and pomegranate peels particles), sliding time (5, 8 and 11 min) and load applied (10, 15 and 20 N). Cleaned off the disc and surface samples before and after performing test wear for each sample using acetone. The wear rate can be calculated by varying the initial and final weight under the influence of previously determined factors, using Eq.(1) below [14 and 15]. The optimal empirical state can be easily determined based on the S/N analysis required to estimate experimental results. In this work, it is preferable the S/N analysis the "lower is better", based on the Eq. (2) [16]. Table 3 displays the levels of the operators utilized in the wear test.

$$\mathrm{W.R} = = \frac{\Delta \mathrm{W}}{\mathrm{S.T}} \qquad (1)$$

where:
W.R: Wear rate (g/mm)
ΔW: The difference weight (g)
S : Speed of sliding (mm/min)
T: Time (min)

$$\frac{S}{N} = -10 \log \frac{1}{n} \left(\sum y^2\right) \qquad (2)$$

where:
n = Number of observations
y^2 = Wear rate

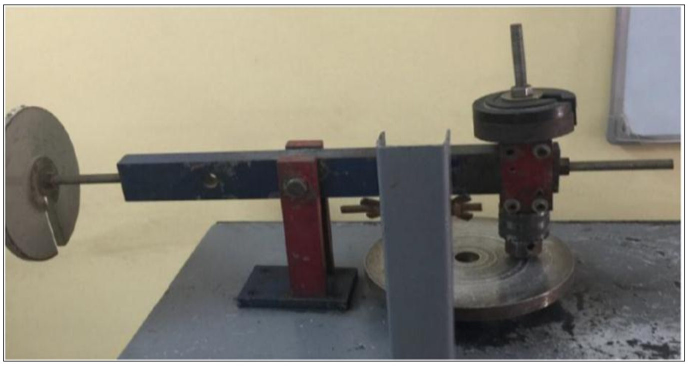


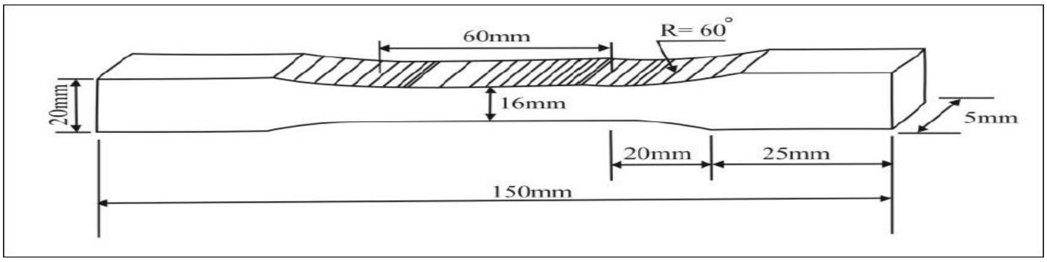
Figure 7: Device wear used in this work

Table 3: Levels of the operators utilized in the wear test.

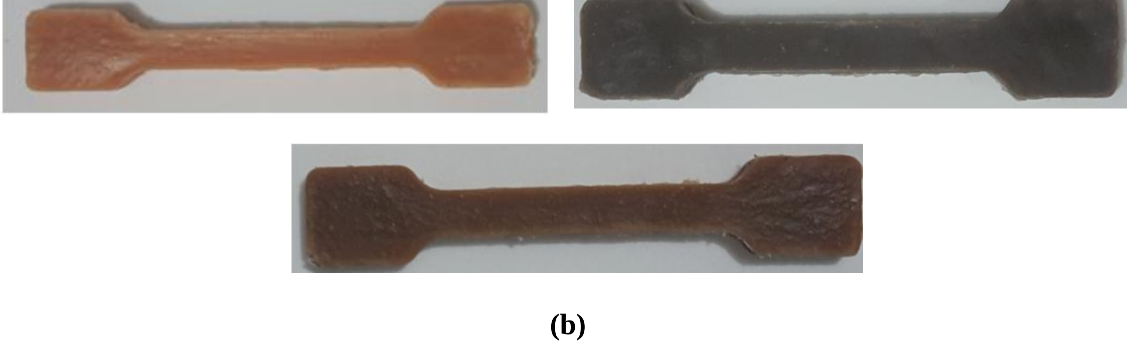
Factors	Level			
	I	II	III	Unit
(A) Samples	Pure PMMA	PMMA+1% Li.	PMMA+2% Li.	%
	PMMA+3% Li.	PMMA+4% Li.	PMMA+5% Li.	
		PMMA+1% Po.	PMMA+2% Po.	
	PMMA+3% Po.	PMMA+4% Po.	PMMA+5% Po.	
(B) Sliding time	5	8	11	Min
(C) Load applied	10	15	20	N

II. Tensile Test

A tensile test procedure using the (UNIVERSAL TESTING MACHINE LARYEE) device with a load applied (50 KN) at a pressure rate (0.5 mm / min). Tensile test samples are cutting into (150 mm) length, (20 mm) width, and (5mm) thickness depending on the ASTM (D 638-03) [17]. Figure 8 shows the dimensions of the samples for the tensile test.



(a)

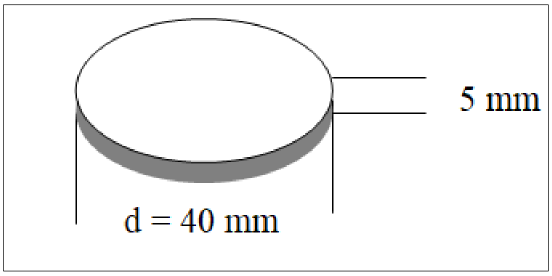


(b)

Figure 8: Tensile test (a) standard, (b) samples empirical of the poly methyl methacrylate filled with licorice particle and pomegranate peels particle.

III. Thermal Test

A thermal test procedure using the ((Lee's Disk) device. Thermal test samples are cutting into (40 mm) diameter and (5 mm) thickness according to ISO-22007 standard [18]. Figure 9 shows the dimensions of the samples for the thermal test.



(a)

(b)

Figure 9: Thermal test (a) standard, (b) samples empirical of the poly methyl methacrylate filled with licorice particle and pomegranate peels particle.

4. Statistical Analyses of Data

The software package MINITAB 18 and Sigma Plot 14.0 was used to achieve statistical analysis. Wear rate values are tabulated and converted into the S/N ratio. The wear, tensile and thermal values were tabulated and transformed into arithmetic means and standard deviations were done using one-way ANOVA with Tukey test, where the aims of the ANOVA-variance analysis is to choose the differences between the averages of several categories or levels of the independent variable and its effect on the dependent variable [19 and 20].

5. Results

I. Wear Test

Tables 4 and 5 appearances the results obtained from the experiments wear behavior (Taguchi L9) tests according to factors the sliding time, weight fraction of fillers and the applied load conducted for all samples. Figures 10 and 11 exhibits the main S/N ratio of all the samples. The wear rate of the samples (PMMA +5% licorice and 5% pomegranate peels particles) was lower compared to pure PMMA samples because the identical dispersal of fillers with matrix polymer gives a major number of covalent bonds that improve the mechanical properties [21]. From the Figures we note that factors A5 (5% wt.), B3 (11 min) and C1 (15N) give the best wear rate resistance (26.9357) (20.0000), therefore the weight fraction of the fillers and sliding time more effectively on the wear tests compared with the load applied, these results agree with [22]. The relation between the weight fraction of filler material and the wear rate is shown in Figures 12 and 13. It is obvious that wear resistance increases with the addition reinforced materials, the samples (PMMA- 5% wt. licorice and 5% wt. pomegranate peels particles) have the best wear resistance approximately (0.045×10^{-6} and 0.10×10^{-6} g /mm) respectively, because increasing the weight fraction for filler material improves the strength of the friction surface by forming a dense protective friction layer, thereby reducing the wear rate, these results are consistent with [23 and 24]. Figures 14 and 15 illustrate the relation between time sliding and wear rate of all samples. The wear rate increases with increasing sliding time from (5 min to

11min) for all samples, because increasing sliding time causes thermal annealing of the composite material, and therefore the polymeric material becomes weak [23]. The Relation between wear rate with the load applied of all samples has been exhibited in Figures 16 and 17. The wear rate increases with the increase in the load applied, but it decreases with the increased weight fraction content. The reason for this is that the presence of reinforcing particles with polymer improves the hardness properties of composites with a decrease in the plastic deformation that occurs when applied the load during wear test [2 and 25].

Table 4: Results wear rate of samples (PMMA - licorice particles).

Exp.	Weight fraction of Filler Wt. (A)	Time sliding Min (B)	Load applied N (C)	Wear Rate (g/ mm)	S/N
1	0%	5	10	1.45×10^{-6}	0.5109
2	0%	8	15	1.19×10^{-6}	0.4227
3	0%	11	20	0.97×10^{-6}	0.2646
4	1%	5	15	0.86×10^{-6}	1.3100
5	1%	8	20	0.78×10^{-6}	2.1581
6	1%	11	10	0.53×10^{-6}	5.5145
7	2%	5	20	0.71×10^{-6}	2.9748
8	2%	8	10	0.35×10^{-6}	9.1186
9	2%	11	15	0.40×10^{-6}	7.9588
10	3%	5	10	0.23×10^{-6}	12.7654
11	3%	8	15	0.18×10^{-6}	14.8945
12	3%	11	20	0.16×10^{-6}	15.9176
13	4%	5	15	0.15×10^{-6}	16.4782
14	4%	8	20	0.20×10^{-6}	13.9794
15	4%	11	10	0.09×10^{-6}	20.9151
16	5%	5	20	0.050×10^{-6}	26.0206
17	5%	8	10	0.052×10^{-6}	25.6799
18	5%	11	15	0.045×10^{-6}	26.9357

Table 5: Results wear rate of samples (PMMA - pomegranate peels particles).

Exp.	Weight fraction of Filler Wt. (A)	Time sliding Min (B)	Load applied N (C)	Wear Rate (g/ mm)	S/N
1	0%	5	10	1.45×10^{-6}	0.5109
2	0%	8	15	1.19×10^{-6}	0.4227
3	0%	11	20	0.97×10^{-6}	0.2646
4	1%	5	15	0.90×10^{-6}	0.9151
5	1%	8	20	0.88×10^{-6}	1.1103
6	1%	11	10	0.60×10^{-6}	4.4370
7	2%	5	20	0.75×10^{-6}	2.4988
8	2%	8	10	0.44×10^{-6}	7.1309
9	2%	11	15	0.47×10^{-6}	6.5580
10	3%	5	10	0.41×10^{-6}	7.7443
11	3%	8	15	0.31×10^{-6}	10.1728
12	3%	11	20	0.29×10^{-6}	10.7520
13	4%	5	15	0.25×10^{-6}	12.0412
14	4%	8	20	0.23×10^{-6}	12.7654
15	4%	11	10	0.19×10^{-6}	14.4249
16	5%	5	20	0.11×10^{-6}	19.1721
17	5%	8	10	0.13×10^{-6}	17.7211
18	5%	11	15	0.10×10^{-6}	20.0000

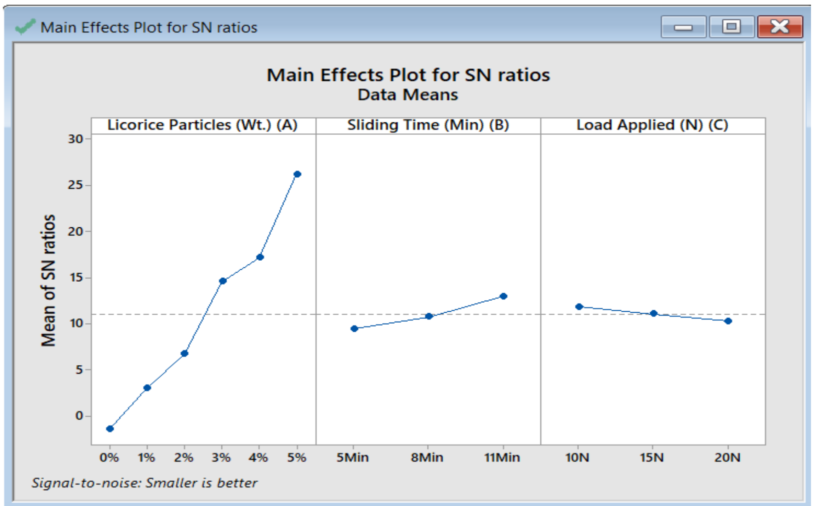


Figure 10: Main S/N ratio of samples (PMMA - licorice particles).

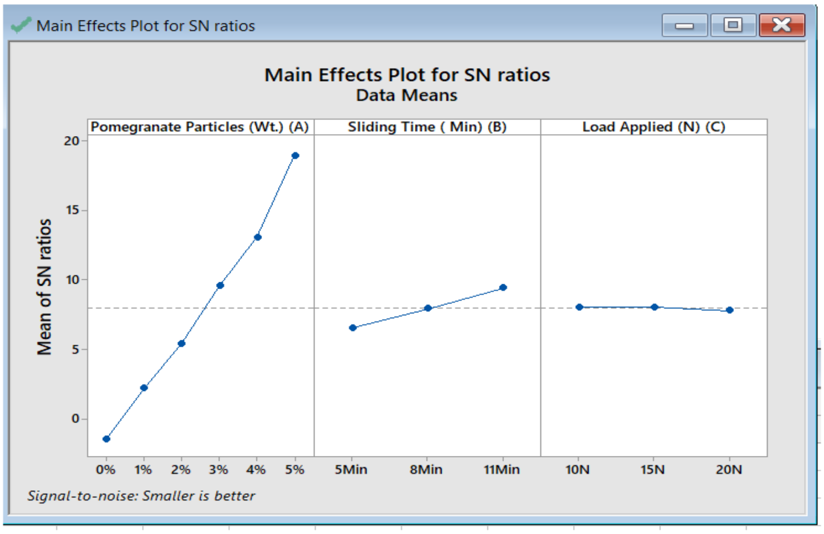


Figure 11: Main S/N ratio of samples (PMMA - pomegranate peels particles).

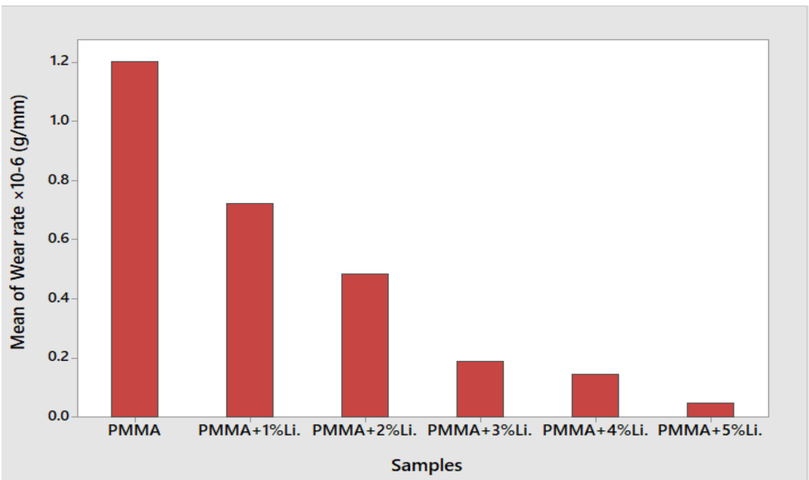


Figure 12: Relation between weight fraction and wear rate of samples (PMMA - licorice particles).

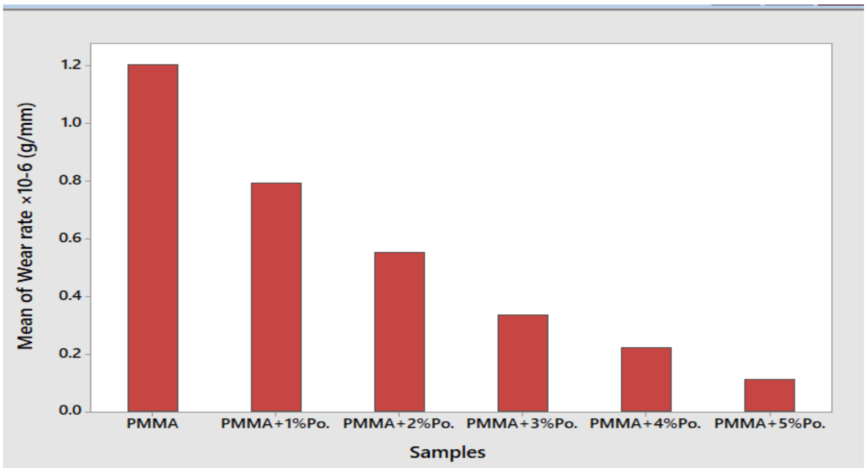


Figure 13: Relation between weight fraction and wear rate of samples (PMMA - pomegranate peels particles).

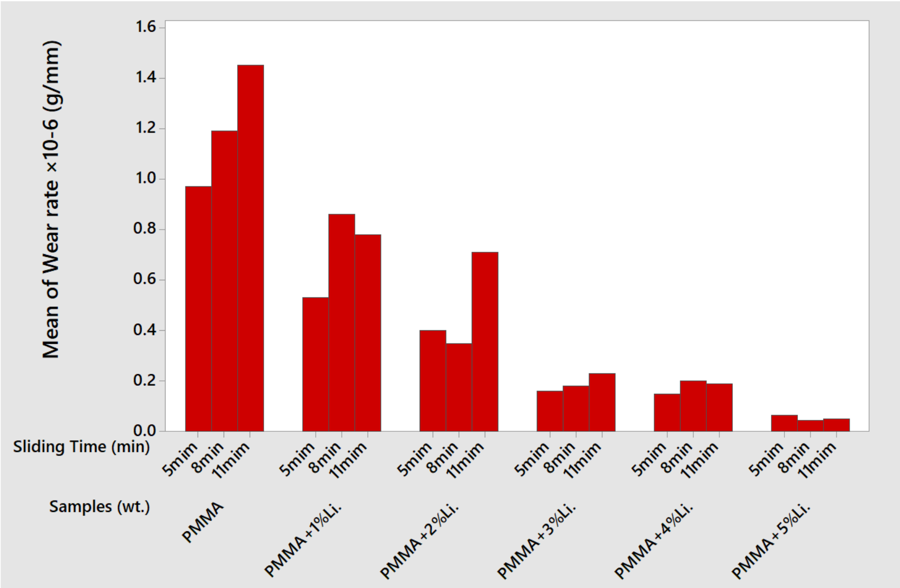


Figure 14: Relation between sliding time and wear rate of samples (PMMA - licorice particles).

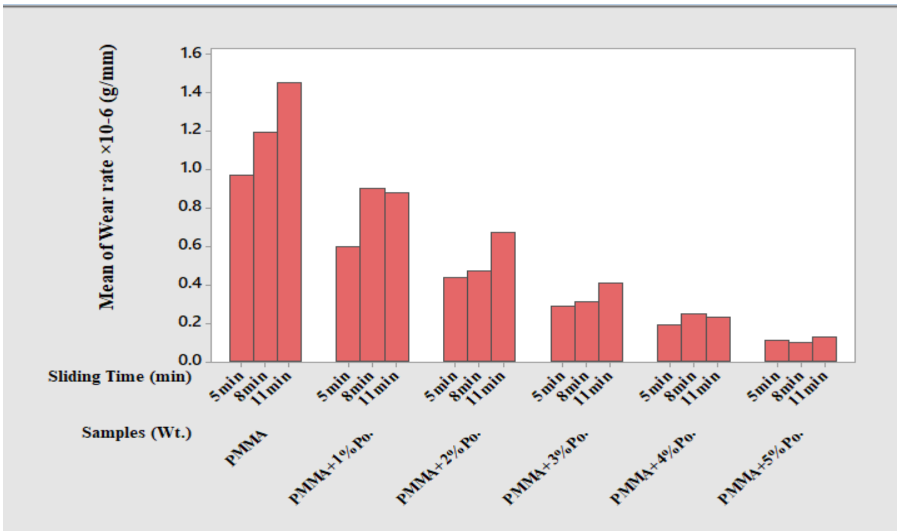


Figure 15: Relation between sliding time and wear rate of samples (PMMA - pomegranate peels particles).

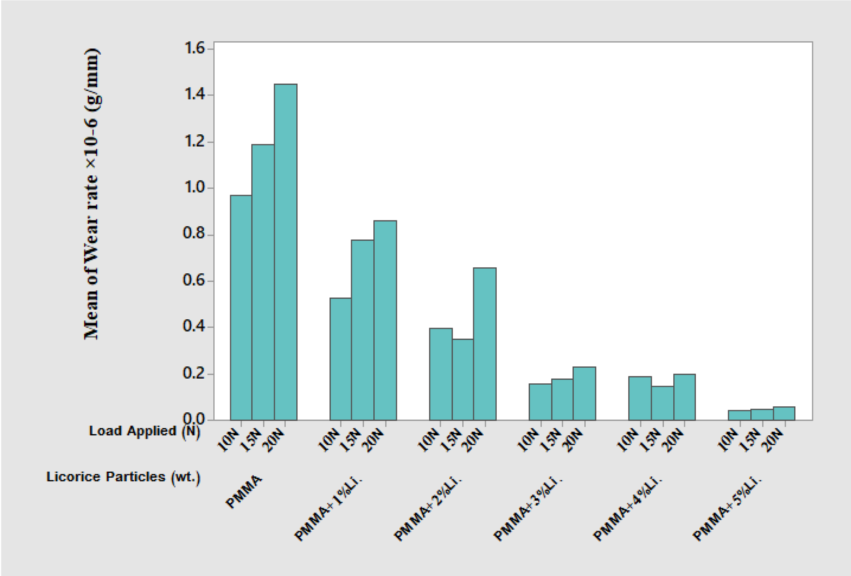


Figure 16: Relation between load applied and wear rate of samples (PMMA - licorice particles).

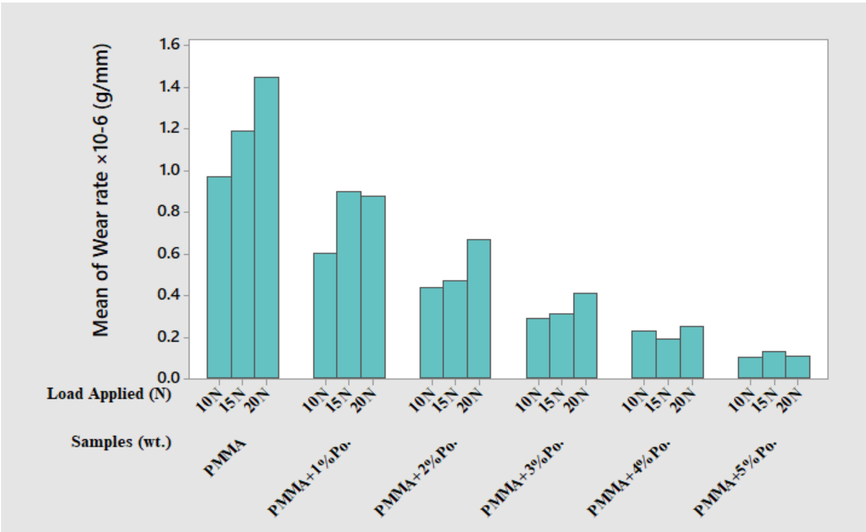


Figure 17: Relation between load applied and wear rate of samples (PMMA - pomegranate peels particles).

II. ANOVA Resultes of Wear Rate

Analysis of variance is one of the statistical methods used to indicate the individual effects of each of the control factors. Tables 6 and 7 represent the results of the variance analysis. The last column of the table represents the value of (P), if the value of (P) is less than (0.050) this means that the factor has a clear effect on the wear behavior, while if the value of (P) is greater than (0.050) means that the factor has a less effect on the wear behavior [26]. For the samples filled with licorice particles and pomegranate peels particles the (P) values of the weight fraction factor and the sliding time factor were (0.001, 0.005, 0.040, 0.044) respectively.On the other hand, the (P) values of the applied load factor (0.052 and 0.055) respectively. The above statistical analysis shows that the wear test parameters were statistically significant in the wear test.

Table 6: Analysis of variance for factors effect on wear test for the samples (PMMA - licorice particles).

Analysis of Variance

Source	DF	SS	MS	F-Value	P-Value
Licorice Particles (wt.)	5	2.88704	0.577407	36.90	0.001
Sliding Time (min)	2	0.13180	0.065902	4.21	0.040
Load Applied (N)	2	0.00252	0.001261	0.08	0.052
Error	8	0.12517	0.015646		
Total	17	3.14653			

Table 7: Analysis of variance for factors effect on wear test for the samples (PMMA - pomegranate peels particles.

Analysis of Variance

Source	DF	SS	MS	F-Value	P-Value
Pomegranate Particles (wt.)	5	2.48396	0.496792	36.09	0.005
Sliding Time (min)	2	0.13068	0.065339	4.75	0.044
Load Applied (N)	2	0.00001	0.000006	0.00	0.055
Error	8	0.11011	0.013764		
Total	17	2.72476			

III. Tensile Properties

Table 8 offered the descriptives and mean values of the tensile strength, modulus of elasticity and elongation percentage for all samples. Figure 18 appear the effect of the weight fraction (licorice particles and pomegranate particles) on the tensile properties. The mean values of tensile strength and modulus of elasticity are increased with increase filler materials, where increase tensile strength and elastic modulus of (55 to 73 MPa, 54 to 70 MPa, 2.400 to 4.800 GPa, 1.800 to 4,300 GPa) when added (5% licorice particles and 5% pomegranate particles to PMMA). Because the adding of particles to the polymer resin improves the normal compatibility between the base material and the reinforcing material, also improves the ability of the sample polymeric composites to transfer the load from the base material to the strengthening material, these results agree with [27and 28]. Also, the adding of licorice particles and pomegranate peels particles to PMMA resin reduces the mean values of elongation percentage compared to control samples PMMA, which decreased from 3.600 to 3.000, 3.500 to 2.800 when added (5% licorice particles and 5% pomegranate particles to PMMA). Because the elongation properties depend on the nature of the behavior of the particles added to the polymer (brittle or ductile), and the licorice and pomegranate particles added to the polymer (PMMA) show fragile behavior, thus increasing the hardness of the composite material and reducing elongation [29]. Besides, we note that the mean value tensile strength, modulus of elasticity and elongation percentage in the samples reinforced with licorice particles - PMMA are slightly better with the samples reinforced with pomegranate peels particles - PMMA and this depends on several factors; the nature of the chemical composition of each, the average granular size, the natural compatibility between the polymer material and the strengthening material, these agree with [9]. Table 9 shows the results of the ANOVA analysis and multiple comparisons (Tukey test) of the tensile test. From the results, we note that there are differences in the mean values between groups of samples greater than expected, where the value (P) of the tensile strength (MPa), modulus of elasticity (GPa) and elongation percentage (%) for the samples (PMMA -licorice particles and pomegranate peels particles) were (0.005, 0.008), (0.004, 0.006), (0.04, 0.05) respectively, ≤ 0.05 this indicates a statistically significant difference. Through multiple comparison procedures (Tukey test), it was found that the weight fractions of the filler materials with the polymeric have a clear effect on improving the tensile properties, these agree with [28].

Table 8: Descriptivist and mean of the tensile properties for all samples.

Samples	N	Mean	Std. Deviation	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
Tensile strength (MPa)							
PMMA	3	51.33	1.528	47.54	55.13	50	53
PMMA+ 1% Li	3	55.00	1.000	52.52	57.48	54	56
PMMA+ 2% Li	3	60.33	1.528	56.54	64.13	59	62
PMMA+ 3% Li	3	65.00	1.100	62.52	67.48	64	66
PMMA+ 4% Li	3	69.00	1.120	66.52	71.48	68	70
PMMA+ 5% Li	3	73.00	1.125	70.52	75.48	72	74
PMMA+ 1% Po	3	54.00	1.000	51.52	56.48	53	55
PMMA+ 2% Po	3	58.00	2.000	53.03	62.97	56	60
PMMA+ 3% Po	3	61.00	1.010	58.52	63.48	60	62
PMMA+ 4% Po	3	65.67	1.528	61.87	69.46	64	67
PMMA+ 5% Po	3	70.00	2.010	64.03	73.97	67	71
Modulus of elasticity (GPa)							
PMMA	3	1.300	.2000	.803	1.797	1.1	1.5
PMMA+ 1% Li	3	2.400	.2020	1.903	2.897	2.2	2.6
PMMA+ 2% Li	3	3.000	.2030	2.503	3.497	2.8	3.2
PMMA+ 3% Li	3	3.600	.2045	3.103	4.097	3.4	3.8
PMMA+ 4% Li	3	4.267	.2055	3.508	5.026	4.0	4.6
PMMA+ 5% Li	3	4.800	.3000	4.552	5.048	4.7	4.9
PMMA+ 1% Po	3	1.800	.2015	1.303	2.297	1.6	2.0
PMMA+ 2% Po	3	2.500	.2025	2.003	2.997	2.3	2.7
PMMA+ 3% Po	3	3.033	.1528	2.654	3.413	2.9	3.2
PMMA+ 4% Po	3	3.610	.2050	3.103	4.097	3.4	3.8
PMMA+ 5% Po	3	4.300	.2060	3.803	4.797	4.1	4.5
Elongation percentage (%)							
PMMA	3	3.700	.2000	3.203	4.197	3.5	3.9
PMMA+ 1% Li	3	3.600	.1990	3.103	4.097	3.4	3.8
PMMA+ 2% Li	3	3.400	.1980	2.903	3.897	3.2	3.6
PMMA+ 3% Li	3	3.300	.1975	2.803	3.797	3.1	3.5
PMMA+ 4% Li	3	3.200	.1960	2.703	3.697	3.0	3.4
PMMA+ 5% Li	3	3.000	.1940	2.752	3.248	2.9	3.1
PMMA+ 1% Po	3	3.500	.1980	3.003	3.997	3.3	3.7
PMMA+ 2% Po	3	3.300	.1975	2.803	3.797	3.1	3.5
PMMA+ 3% Po	3	3.200	.1965	2.703	3.697	3.0	3.4
PMMA+ 4% Po	3	2.900	.1955	2.652	3.148	2.8	3.0
PMMA+ 5% Po	3	2.800	.1900	2.552	3.048	2.7	2.9

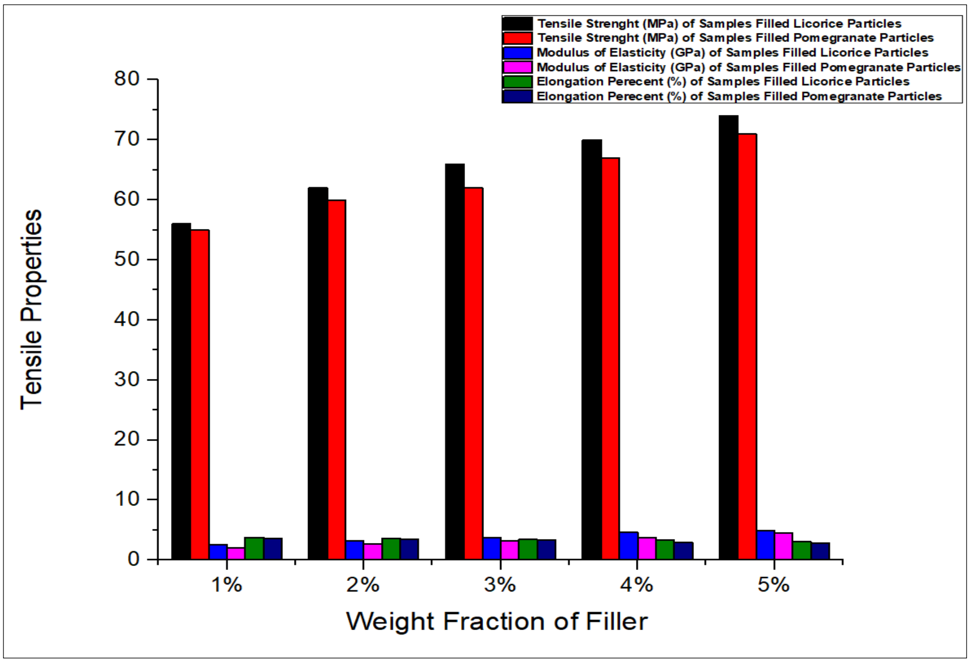


Figure 18: Tensile properties of the samples PMMA - licorice particles and PMMA- pomegranate peels particles.

Table 9: ANOVA analysis and multiple comparision (Tukey Test) of the tensile properties.

One Way Analysis of Variance (SigmaPlot 14)

PMMA- Li.	N	Sum of Squares	Mean Square	F	P
Tensile Strength (MPa)	18	1032.278	206.456	142.931	0.005
Modulus of Elasticity (GPa)	18	24.429	4.886	111.324	0.004
Elongation Perecent (%)	18	1.000	0.200	5.714	0.04

PMMA- Po.	N	Sum of Squares	Mean Square	F	P
Tensile Strength (MPa)	18	675.111	135.022	18.003	0.008
Modulus of Elasticity (GPa)	18	18.818	3.764	101.110	0.006
Elongation Perecent (%)	18	1.780	0.356	11.867	0.05

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference.

To isolate the group or groups that differ from the others use a multiple comparison procedure.

***All Pairwise Multiple Comparison Procedures (Tukey Test):**

Comparison of samples PMMA-Li.	Diff of Ranks	q	P	P<0.050
Tensile Stren vs Modulus of El	54.500	4.168	0.009	Yes
Tensile Stren vs Elongation at	53.500	4.091	0.011	Yes
Elongation at vs Modulus of El	1.000	0.0765	0.048	yes

Comparison of samples PMMA-Po.	Diff of Ranks	q	P	P<0.050
Tensile Stren vs Modulus of El	59.000	4.512	0.004	Yes
Tensile Stren vs Elongation at	49.000	3.747	0.022	Yes
Elongation at vs Modulus of El	10.000	0.765	0.050	yes

IV. Thermal Properties

Table 10 presented the descriptives and mean values of the thermal conductivity and thermal diffusivity for all samples. Figure 19 appear the effect of the weight fraction (licorice particles and pomegranate particles) on the thermal properties. The addition (1%wt. to 5%wt.) of the licorice particles and pomegranate peels into PMMA resin lead to an increase in the thermal conductivity and thermal diffusion of the denture base compared to the pure sample without any filler, since the thermal properties depend on several factors, including the granular size of the reinforced particles, the natural correlation and the density of the reinforced particles [11]. The best mean values of thermal conductivity and thermal diffusion were found in the samples (PMMA + 5% wt. licorice particles and 5% wt. pomegranate peels particles) (.5600, .5400 W/mk), (.3800, 02800 mm^2/sec) respectively. Thermal properties of the samples reinforced with licorice particles are better compared to the samples reinforced with the pomegranate peels particles, this case can be explained by the fact that the thermal properties depend on the density, where the density of licorice particles higher than the density of the pomegranate peels particles, these results agree with [30]. The results of the ANOVA analysis and multiple comparisons (Tukey test) of the thermal properties are exhibited in Table 11. It was found that there were differences in the mean values between the groups of samples greater than expected, where the value (P) of thermal conductivity (W/mk) and thermal diffusivity (mm^2/sec of the samples (PMMA- licorice particles, PMMA-pomegranate peels particles) were (0.0480, 0.0464), (0.0481, 0.0327), respectively $\leq$0.05, this indicates a statistically significant difference. Through multiple comparison procedures (Tukey test) between thermal conductivity and thermal diffusivity, it was found that P = 0.027 for samples (PMMA - licorice particles) and P = 0.027 for samples (PMMA-pomegranate peels particles), so the weight fraction of fillers with the polymeric base material has a pronounced effect on improving thermal properties, these results agree with [11 and 28].

Table 10: Descriptives and mean of the thermal properties of all samples.

Samples	N	Mean	Std. Deviation	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
Thermal Conductivity (W/m k)							
PMMA	3	.2400	.02005	.1903	.2897	0.22	.26
PMMA+ 1% Li	3	.3100	.02010	.2603	.3597	.29	.33
PMMA+ 2% Li	3	.3700	.02022	.3203	.4197	.35	.39
PMMA+ 3% Li	3	.4300	.02050	.3803	.4797	.41	.45
PMMA+ 4% Li	3	.4900	.02066	.4403	.5397	.47	.51
PMMA+ 5% Li	3	.5600	.02090	.5103	.6097	.54	.58
PMMA+ 1% Po	3	.3000	.02000	.2503	.3497	.28	.32
PMMA+ 2% Po	3	.3600	.02010	.3103	.4097	.34	.38
PMMA+ 3% Po	3	.4200	.02020	.3703	.4697	.40	.44
PMMA+ 4% Po	3	.4800	.02028	.4303	.5297	.46	.50
PMMA+ 5% Po	3	.5400	.02035	.4903	.5897	.52	.56
Thermal Diffusivity (mm^2/sec)							
PMMA	3	.0700	.02000	.0203	.1197	.05	.09
PMMA+ 1% Li	3	.1300	.02022	.0803	.1797	.11	.15
PMMA+ 2% Li	3	.1800	.02035	.1303	.2297	.16	.20
PMMA+ 3% Li	3	.2533	.03055	.1774	.3292	.22	.28
PMMA+ 4% Li	3	.3200	.03060	.2703	.3697	.30	.34
PMMA+ 5% Li	3	.3800	.03075	.3303	.4297	.36	.40
PMMA+ 1% Po	3	.0967	.01528	.0587	.1346	.08	.11
PMMA+ 2% Po	3	.1300	.02000	.0803	.1797	.11	.15
PMMA+ 3% Po	3	.1700	.02040	.1203	.2197	.15	.19
PMMA+ 4% Po	3	.2200	.02050	.1703	.2697	.20	.24
PMMA+ 5% Po	3	.2800	.02075	.2303	.3297	.26	.30

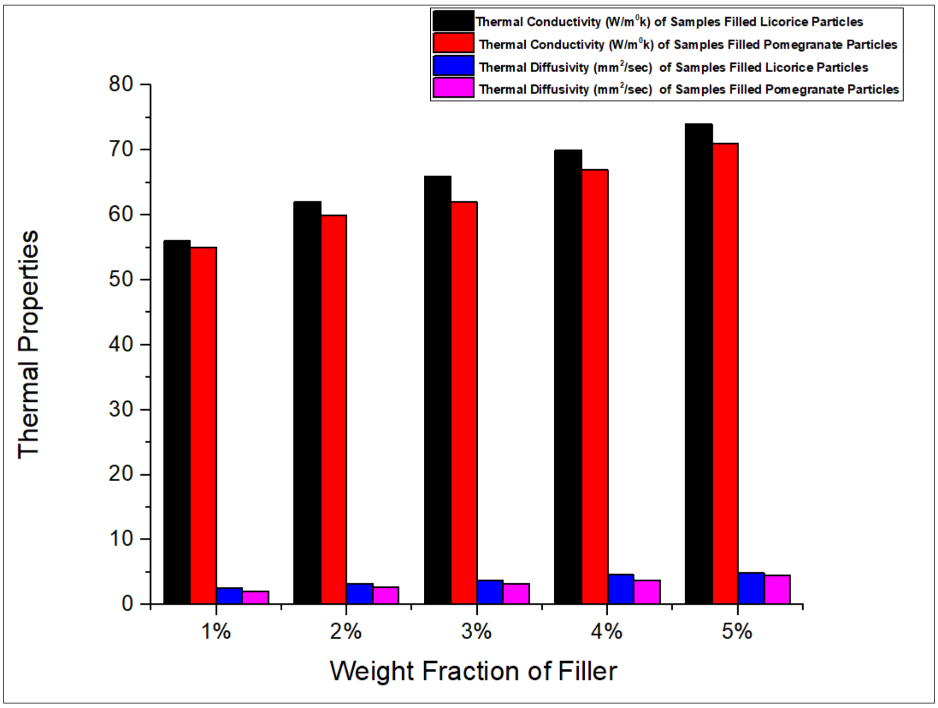


Figure 19: Thermal properties of the samples PMMA - licorice particles and PMMA- pomegranate peels particles.

Table 11: ANOVA analysis and multiple comparison (Tukey Test) of the thermal properties.

One Way Analysis of Variance (SigmaPlot 14)

PMMA-Li	N	Missing	Mean	Std Dev	SEM
Thermal Conductivity (W/m.k)	6	0	0.420	0.118	0.0480
Thermal Diffusivity (mm²/sec)	6	0	0.243	0.118	0.0481

Source of Variation	DF	SS	MS	F	P
Between Groups	1	0.0936	0.0936	6.759	0.027
Residual	10	0.139	0.0139		
Total	11	0.232			

PMMA-Po.	N	Missing	Mean	Std Dev	SEM
Thermal Conductivity (W/m.k)	6	0	0.407	0.114	0.0464
Thermal Diffusivity (mm²/sec)	6	0	0.180	0.0800	0.0327

Source of Variation	DF	SS	MS	F	P
Between Groups	1	0.154	0.154	15.967	0.003
Residual	10	0.0965	0.00965		
Total	11	0.251			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.027).

*** All Pairwise Multiple Comparison Procedures (Tukey Test):**

Comparison of samples PMMA-Li.	Diff of Means	p	q	P	P<0.050
Thermal Cond vs. Thermal Diff	0.177	2	3.677	0.027	Yes

Comparison of samples PMMA-Po.	Diff of Means	p	q	P	P<0.050
Thermal Cond vs. Thermal Diff	0.227	2	5.651	0.003	Yes

7. Conclusions

This study has focused on wear behavior, tensile and thermal properties of polymethyl methacrylate reinforced with licorice particles and pomegranate peel particles. The wear rate increases with increasing sliding time (5 to 11 min) and increased load applied (10 to 20 N), while the wear rate decreases with the increasing weight fraction of (1% wt. to 5% wt.) of the licorice particles and pomegranate peel particles. The adding 5% wt.of licorice particles and pomegranate peel particles to the PMMA polymer increase the wear resistance rate compared to the control sample without any addition at the variables (11 min) sliding time and (10 N) load applied. The presence of licorice and pomegranate peels particles with polymer material lead to increased tensile strength, modulus of elasticity, thermal conductivity, and thermal diffusion. The values of elongation at break decreased with the addition of particles to the PMMA polymer matrix. From the ANOVA analysis and multiple comparisons (Tukey Test), it was found that there were differences in the mean values between the groups of samples greater than expected.

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