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Fabrication of Natural Gelcoats (Epoxy/ Pumpkin Peels Fibers) Composites with High Mechanical and Thermal Properties

Afya Qasem Fadhel
Department of Physics, College of Education for Pure Science (Ibn-AL-Haitham),University of Baghdad, Baghdad,Iraq.
afya.qasem1204a@ihcoedu.uobaghdad.edu.iq

Widad Hamdi Jassim
Department of Physics, College of Education for Pure Science (Ibn-AL-Haitham),University of Baghdad, Baghdad,Iraq.
widad.h.j@ihcoedu.uobaghdad.edu.iq

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Abstract

Pumpkin waste powder was used as a coloring and strengthening filler in epoxy to prepare a natural gelcoat. The Pumpkin powder was mixed with different weight ratios (1, 2, 3, 4, 5, 6, 7, and 8%) to the epoxy matrix to select the best value of powder addition. The effect of the pumpkin particle size on the mechanical properties (impact, flexural, hardness, and wear loss) using two different sizes (2.5 and 1.25 microns) was studied. The impact strength increased from (10.09 KJ/ m^2) for neat epoxy to (14.79 KJ/ m^2) for epoxy with 1% of micron pumpkin fibers (MPF) with a particle size 2.5 micrometer and (14.21 KJ/ m^2) for epoxy with 4% (1.25 MPF), flexural strength increased from (41.94 MPa) for neat epoxy to (~ 46 MPa) for epoxy with 1% of 2.5 MPF and to (50.17 MPa) for epoxy with 4% of 1.25 MPF, hardness of neat epoxy was (~ 77) and almost maintained its value for epoxy with 1% of 2.5 MPF and for epoxy with 4% of 1.25 MPF. At almost the weight fractions addition of pumpkin fibers to epoxy, the (EP/1.25MPF) composite shows a higher wear resistance than the (EP/2.5MPF) composite. The density, thermal conductivity, and water diffusion (for 1-4 weeks' immersion) of (EP/2.5MPF) and (EP/1.25MPF) composites were carried out at different weight percentages of pumpkin fibers. SEM and EDS techniques were employed to fix the microstructure and the elemental composition of (EP/2.5MPF) and (EP/1.25MPF) composites, respectively. The internal structure of the composites has been linked with their macroscopic characteristics, such as the color degree of natural gelcoats and their mechanical and thermal properties.

Keywords: Pumpkin Fibers, Epoxy, Mechanical Properties, Thermal Conductivity, SEM, EDX, Water Diffusion.

1. Introduction

Epoxy resins have excellent mechanical and chemical properties that enable them to be used as a substitute for other materials, such as metals and ceramics. In many applications, epoxy is also suitable for filling fibers with different particle sizes[1–4]. Fibers of natural origin are an excellent alternative to petroleum-based ones. The plant fibers have lightweight with high strength, are environmentally friendly, and inexpensive. All these features make it a good choice for improving the properties of epoxy [5, 6]. Pumpkin is one of the most common plants found around the world that can be used as a reinforcement to the polymer matrix and for coloring, usually plant fibers contain lignin, hemicellulose and cellulose[7]. Plant fibers have high mechanical properties like toughness and strength with low density; therefore, it was used by some researchers in several ways and for several applications [7]. Many researchers have changed the properties of epoxy by adding different types of natural fibers with varying particle sizes to reach good properties for the final composite to be used in a specific application. Tuan and Thi have used banana fibers by weight ratios (10, 15, 20, and 25%) to improve epoxy's fire resistance and thermal properties [8]. Wafaa used the carrot fibers of two different sizes, less than 50 microns and between (100 – 150 microns) in four weight percentages of loading (10, 20, 30, and 40%) to improve the impact strength, hardness of epoxy [9]. Qahtan Adnan and Mayyadah S. Abed have used the nanoparticles leaf of pumpkin and thyme with weight ratios (0, 0.5, 1, 1.5, and 2%) to increase the impact and compressive strength of epoxy [5]. In this research, pumpkin peel fibers with two different sub micron sizes (2.5 and 1.25 µm) were added to epoxy with varying percentages of weight (1, 2, 3, 4, 5, 6, 7, and 8%) to use these epoxy composites as natural gelcoats by improving its mechanical properties, like (impact, flexural, hardness and wear loss), and also the improvement in epoxy resistance to both thermal and water diffusions.

2. Experimental

2.1 Materials

Epoxy resin (sikadur-52) American made was used as a matrix. This resin hardens by mixing it with its hardener by a ratio of 2:1. The density of epoxy was (1.1 kg /m2) at the temperature (of 25oC). Pumpkin fibers were used as fillers, where the pumpkin was washed well to get rid of dust, then pumpkin peels, which are considered waste that has been added for use.

2-2 Sample Preparation

Pumpkin peels were dried firstly by the sun's heat for seven days, then by the oven's heat for five hours at a temperature (of 60oC). The dried peels were crushed and grilled using the grinder, then milled into two different submicron sizes (2.5 and 1.25 µm) using the milling device (NQM- 0.4 ball mill) for 30 minutes, respectively. **Figure (1)** shows the pumpkin peels with their powders, while **Figure (2)** shows the average volume distribution particle size of the two submicron pumpkin fibers.

Figure 1. (a) pumpkin peels (b) dried pumpkin peels (C)1.25 micron pumpkin fibers(d) 2.5 micron pumpkin fibers

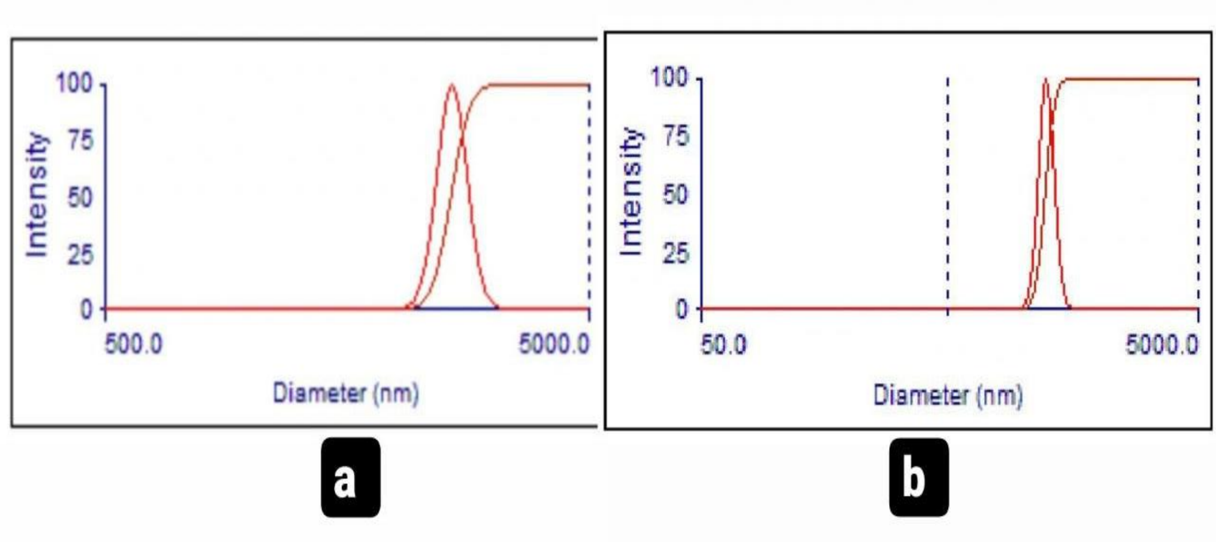

Figure 2. The distribution of volume particle size for pumpkin micro-fiber a) 2.5 micron b) 1.25 micron

2-3 Composites Casting

Pumpkin fibers were mixed with epoxy at different weight percentages (1- 8%). The mixtures of (EP / 2.5MPF) and (EP / 1.25MPF) were poured into silicone molds; Vaseline was used to rub the cavities of molds for easy removal of composite sheets. The mixtures of (EP / 2. 5MPF) and (EP / 1.25MPF) were allowed to cure in the mold for one to two days at room temperature. The sample was cast according to the international standard (ASTM).

3.Measurements and Tests

3-1 Mechanical Tests

3-1-1 Impact test

Figure (3) shows the specimens of (EP/ 2.5MPF) and (EP /1.25MPF) composites, which were prepared with dimensions (0.8 × 1 × 10 cm). The impact Charpy test was performed according to (ISO – 179) international system.

Figure 3: impact samples test of epoxy with different weight percentages of pumpkin fibers EP / 2.5MPF b) EP / 1.25MPF

3-1-2 Flexural Test

Three – point bending was used to determine the flexural strength of specimen with dimensions (10 × 1 × 0.4 cm), this test done according to (ASTM – D790).

3-1-3 Hardness Test

To measure the hardness of the (EP / 2.5MPF) and (EP / 1.25MPF) composites surfaces, Shore (D) test (model device TH 210, Italy) was used.

3-1-4 Wear Test

The wear rate of (EP / 2.5 MPF) and (EP / 1.25MPF) composites specimens, as shown in **figure (4)** were carried out using pin – on – disk, with (500 gm) load applied, the distance from the center of specimen to the center of iron disk was (r = 9 cm) the sample rotates around the center by the number of turns (N= 375 cycle / min) for period of time (t = 5 min). To calculate the wear rate of specimen , equation (1) was used [10].

Wear rate = $\frac{w_2 - w_1}{2\pi n r t}$ ……………..(1)

Where;

w_2 : Theinitial weight of specimen.

w_1 : The final weight of specimen.

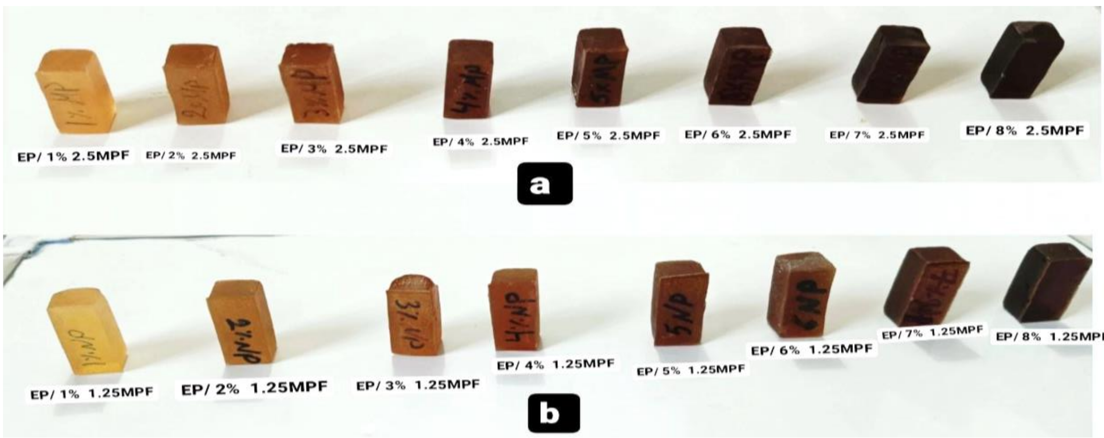

Figure 4. Wear rate samples for a) EP/2.5μm pumpkin fibers b) EP/1.25μm pumpkin fibers

3-2 Physical Properties

3-2-1 Density Measurement

By pressing a quantity of powders of 2.5 pumpkin fibers and 1.25 pumpkin fibers, using a piston to make a circular shape, and dividing the mass by the volume, the densities can be found.

3-2-2 Thermal Conductivity

To determine the thermal conductivity of (EP / 2.5 MPF) and (EP / 1.25MPF) specimens, a lee disk device was used. **Figure (5)** shows different samples of thermal conductivity tests.

Figure 5. Thermal Conductivity Specimens a) EP / 2.5MPF b) EP / 1. 25MPF

3-2-3 Water Absorption

The samples of (4×4×4 mm2) were cut from (EP/2.5MPF) and (EP/1.25MPF) composites. These samples were weighed before and after being immersed in water for different times (1, 2, 3, and 4 weeks).

The ASTM D570 was used to determine the water uptake using equation (2).

Water uptake = $(W_{after} - W_{before}) / W_{before}$ …………(2) [11].

3-3 Scanning Electron Microscopy (SEM)

We examined the microstructure of (EP / 2.5 MPF) and (EP / 1.25MPF) composites and determined the homogeneity of these samples. They were coated with a thin layer of gold to be photographed in the electronic scanning device (SEM inspect s 50) manufactured by (FEI) in Howland.

3-4 Energy Dispersive Spectroscopy (EDS)

The composition of (EP / 2.5 MPF) and (EP / 1.25MPF) composites was fixed using (EDS) technique (Procar) made in Germany, equipped with the SEM technique.

4.Results and Discussion

4-1 Mechanical Tests

4-1-1 Impact Test

Impact strength shows the extent of the materials ability to absorb energy before it breaks after applying impact force [12].

Figure (6) shows the impact strength of (EP / 2.5MPF) at different weight percentages of pumpkin fibers, where the impact strength values increase with an increase in the percentages of pumpkin fibers with a particle size 2.5 micro from (10.09 kJ / m2) for pure epoxy to the maximum value (14.79 kJ / m2) with (1 % 2. 5MPF) content. Down to the minimum value (9.61 kJ / m2) with (7% 2. 5MPF) content, this behavior of the impact strength curve is similar to that found by (Seenaa et al.) [10].
The addition of pumpkin fibers with of particle size of 2.5 micro to epoxy with concentrations less than (5 wt %) improves the impact strength of the (EP / 2.5MPF) composites because these small proportions of fibers act as strength centers in the epoxy matrix [12].

By adding the pumpkin fibers with smaller particle size (1.25 microns) to epoxy, the impact strength of epoxy will improve to reach the highest value (14.21 kJ /m2) by adding (4% of 1.25MPF). This is because of the effect of both particle size and the percentage of addition factors [5].
Figure (6) also shows that the impact strength of (EP/2.5MPF) composite was higher than that of (EP / 1.25MPF) at the (1% wt.), this a because the bigger particle size works to fill the defects of vacant space in the epoxy matrix at this small weight ratio of addition. Still, with an increase in the weight ratios (2-5 %) of pumpkin fibers to epoxy, the values of impact strength of (EP/2.5MPF) and (EP / 1.25MPF) composites will converge.
At higher weight ratios of addition (6-8%), the (EP/1.25MPF) composites have a higher value of impact strength than that of (EP/2.5MPF) composites; this is because of agglomeration of the smaller particle size [5].

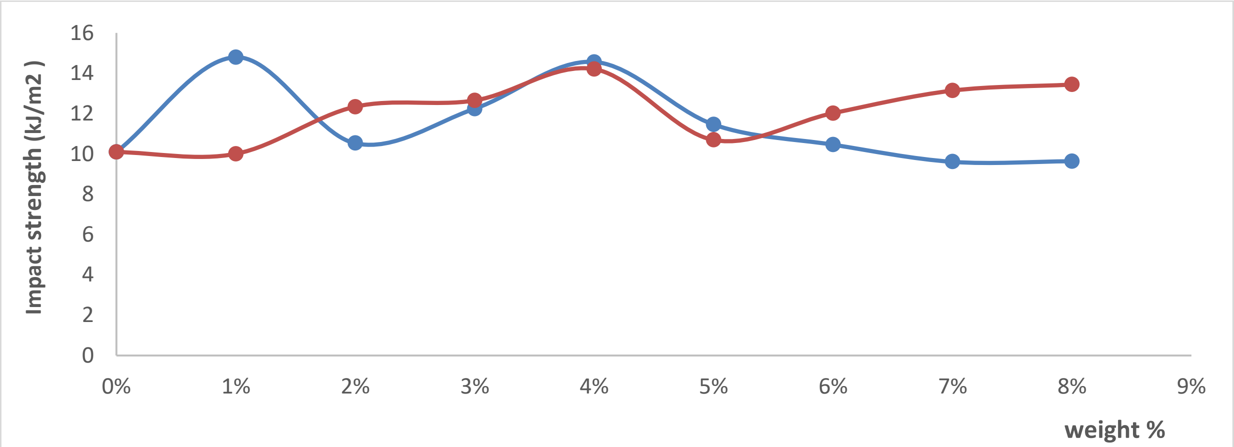

Figure 6. Comparison between the impact strength of (EP / 2.5MPF) and (EP / 1.25MPF) at different weight ratios

4-1-2 Flexural Test

Flexural strength indicates the material's resistance to bending when applying an external force [12].
Figure (7) shows that the flexural strength increases from (41.94 MPa) for neat epoxy, reaching a higher value (45.88 MPa) for (EP/ 1% 2.5MPF) and reduces to a lower value (33.89 MPa) for (EP/ 5% 2.5MPF) composite. This means that(1% 2.5MPF) is a sufficient ratio to achieve good bonding between micro pumpkin fibers and epoxy matrix [5]. (EP/4% 1.25MPF) composite has higher flexural strength (50.17 MPa) that mean flexural strength of this composite has increased by about

20% over its value for epoxy, then decreased to minim value (33.32 MPa) for (EP / 6 % 1.25MPF) composite, these results are a good agreement with (sunny)[13].

(EP/1.25MPF) composite has a higher flexural strength value than (EP/2.5MPF) composite at a 4% weight percentage of addition, but (EP/2.5MPF) composite has a higher value of flexural strength at a small percentage of pumpkin fibers (1%).

This means that the flexural strength values depend on the final result of the reaction of both factors (particle size and percentages of addition).

At low percentages of addition (less than 4%), epoxy composites reinforced with high particle sizes (2.5%) and overcome the (EP/1.25MPF) composites. The matter is wholly reversed at higher than 4% addition rates, where epoxy composites reinforced with lower particle size (1.25 microns) have a higher value of flexural strength than (EP/2.5MPF) composites.

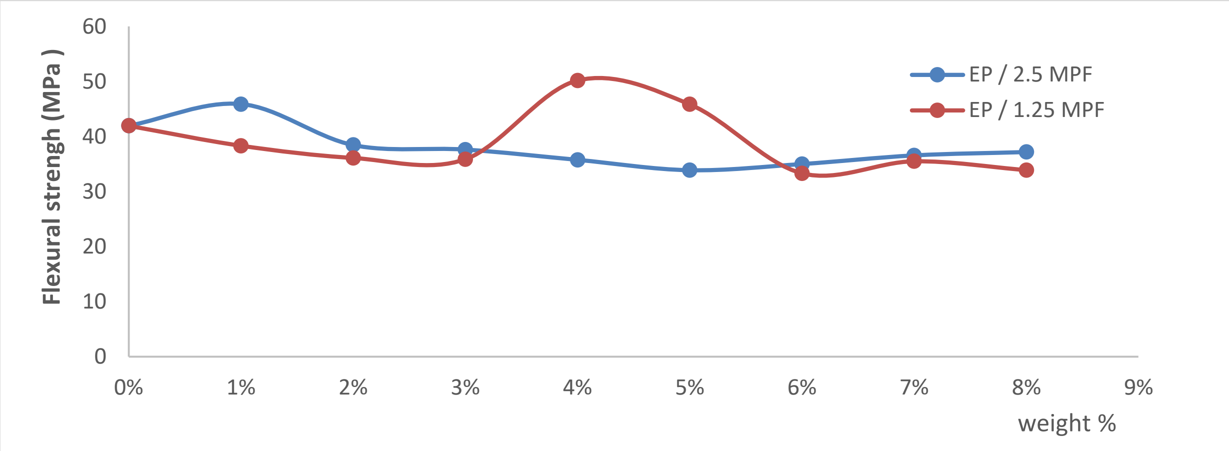

Figure 7. Comparison between the flexural strength of (EP / 2.5MPF) and (EP / 1.25MPF) at different weight ratios

4-1-3 Hardness Test

Figure (8) shows that (EP/2.5MPF) composite at different weight percentage has a slightly lower value of hardness compared to the hardness of neat epoxy (76.53), and the percentage of addition (1%) remains almost conservative on the resistance of the (EP/2.5 MPF) composite to the indentation.

(EP/1.25 MPF) composites have a higher hardness value at the (4 %) addition percentage. This behavior of the hardness curve is similar to the results in research [5].

By comparing between the hardness values of the two composites, the hardness value at (1%) percentage of addition to epoxy reinforced with high particle sizes (2.5%) overcome the hardness value of (EP/1.25MPF) composite. The matter is completely reversed at addition rates of (2 % - 5%), where epoxy composites reinforced with lower particle size (1.25 microns) of pumpkin fibers have a higher value of flexural strength than (EP/2.5MPF) composites. This is because of the excellent dispersion of smaller particle sizes between the chains of the epoxy matrix at these rates of additions. Still, at higher rates of additions (6% - 8%), the hardness values of (EP/1.25MPF) composites will reduce. This may be due to the agglomeration of pumpkin particles in the epoxy matrix.

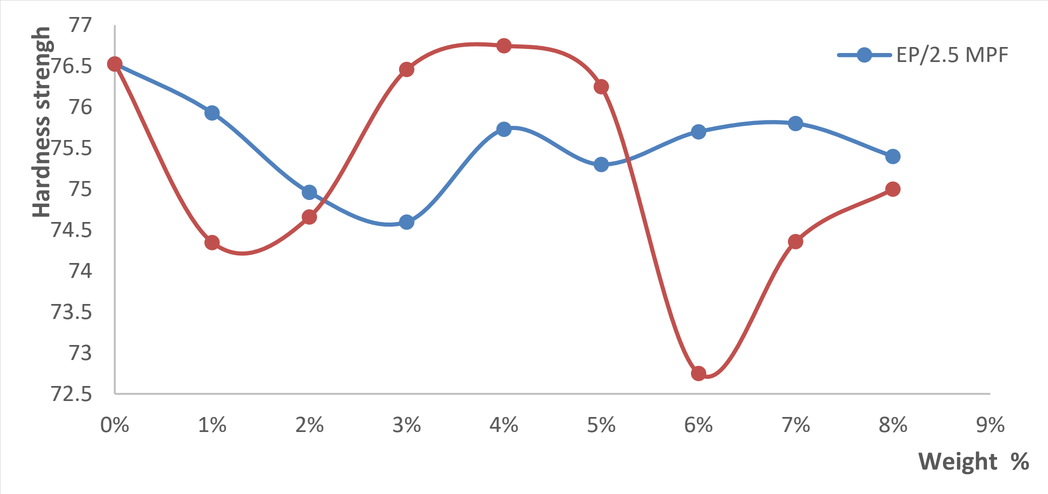

Figure 8. Comparison between the hardness of (EP / 2.5MPF) and (EP / 1.25MPF) at different weight ratios

4-1-4 Wear Resistance

The wear loss as a function of the weight percentage of micro pumpkin fibers with particle size (2.5 microns) in epoxy is shown in **Figure (9).** At the low percentage of powder addition (1%), the wear-resistance properties of (the EP/ 2.5 micro pumpkin fibers) composite will be significantly improved. Still, adding pumpkin fibers at weight fractions of 2% to 5% will increase the wear loss in (EP/ 2.5 micro pumpkin fibers) composites. This may be due to the rough nature of pumpkin peel fibers.

The non-ductile nature of pumpkin fibers will increase the wear loss in (EP /MPF) composite. Still, by minimizing the particle size of pumpkin fibers to half, the wear resistance of (EP / 1.25MPF) composites will increase at the weight ratios of pumpkin fibers (2% - 4%) compared with the weight ratios of 1% and 5%).

(EP / 1.25MPF) composites have a higher wear resistance than (EP / 2.5MPF) composites at weight fractions of addition (2% - 8%). But (EP / 2.5MPF) composites have high wear resistance at the low percentage of adding (1%) with comparing with (EP / 1.25MPF) composite at this weight ratio because of the excellent dispersion of the smaller sizes of pumpkin particles in the epoxy matrix. These results are agreed with the other mechanical properties.

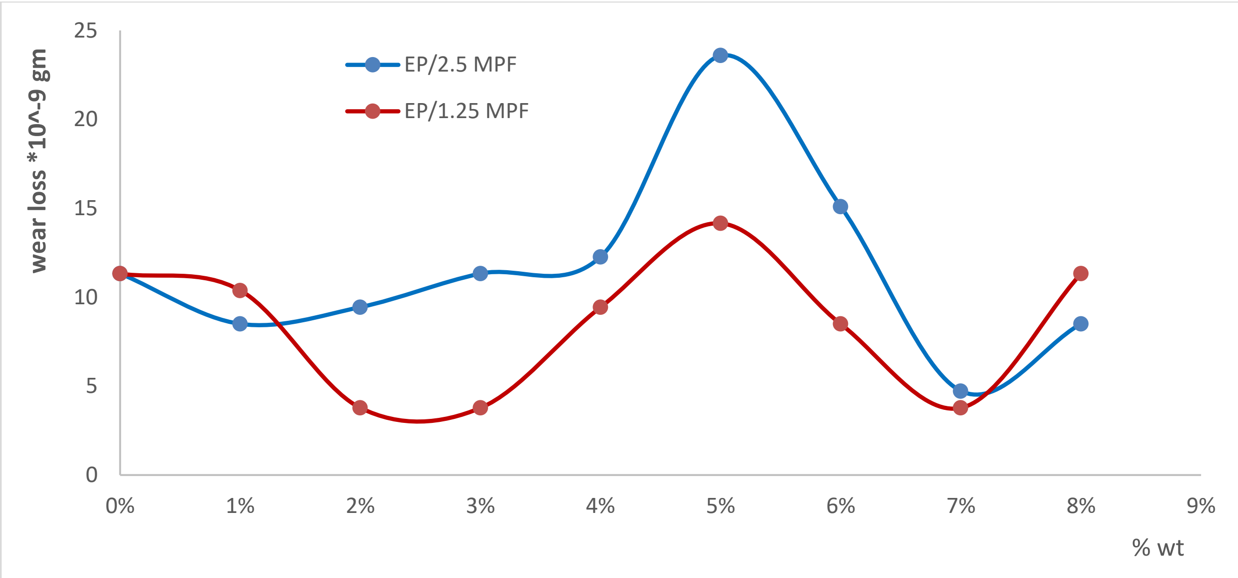

Figure 9. Wear rates of (EP / 2.5MPF) and(EP / 1.25MPF) composites

4-2- Physical Properties

4-2-1 Density Measurement

The density (ρ) of (EP/2.5 MPF) and (EP/1.25MPF) composites are calculated by rule of matrix [13].

$$\rho = \rho_m w_m + \rho_r w_r \ldots\ldots\ldots\ldots\ldots (3)$$

Where:

ρ_m and ρ_r : are the density of matrix and filler, respectively.

w_m and w_r: are the weight fractions of matrix and filler, respectively.

The density of (EP/2.5MPF) and (EP/1.25MPF) composites as a function of the weight ratio of pumpkin peel fibers are shown in **Figure (10).** The density of neat epoxy decreased from (1.15 gm / cm^3) to lower values (1.129gm/ cm^3) and (1.1388gm/ cm^3) at a weight ratio 7%with the addition of the pumpkin peel fibers to epoxy with particle size 2.5microns and 1.25 microns respectively. The density values decrease for (EP/2.5MPF) and (EP/1.25MPF) composites, only at small percentages of addition, but it increases when the weight ratios are high (above 7 %). This agreed with the results (Sunny et al.) [13].

By comparison between the densities of both (EP/2.5MPF) and (P/1.25MPF) composites, the (P/1.25MPF) has higher density values at the same addition values, whereas small sizes particles have a very high surface area to volume rate (high powder densities), there for the incorporation of these small particles into materials significantly improves their mechanical properties [14].

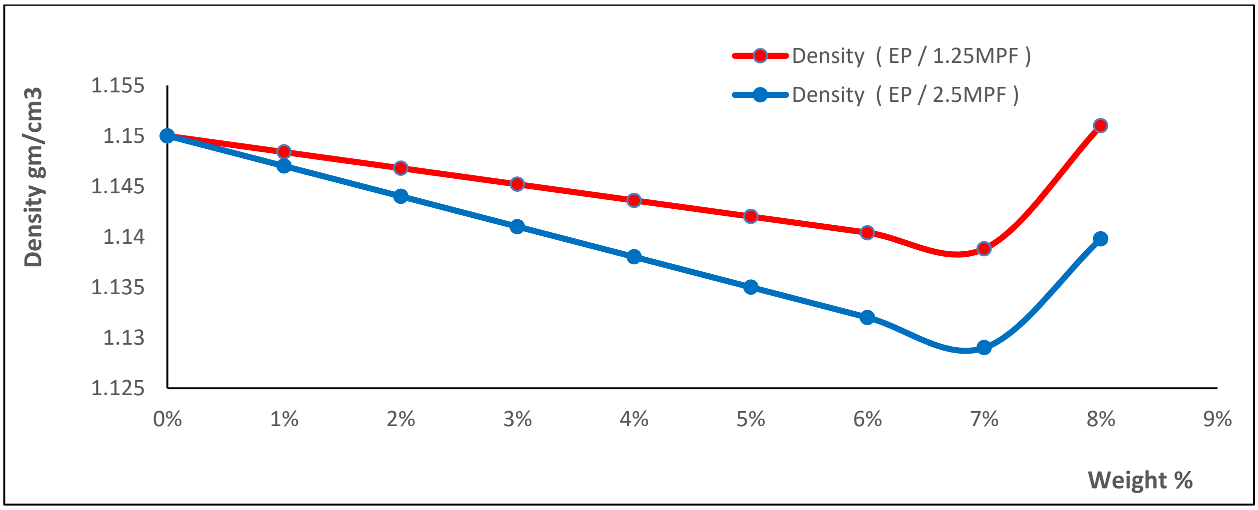

Figure 10. Comparison between the densities of (EP/2.5 MPF) & (EP/ 1.25MPF) composites

4-2-2 Thermal Conductivity

Figure (11) shows that the neat epoxy has thermal conductivity (0.48938 W /m. °C). This value will be changed by adding micro pumpkin fibers of two sizes (2.5 and 1.25 microns) to epoxy. The lowest thermal conductivity value means the best value for composite thermal insulation.

(EP/1% 2.5MPF) and (EP/ 4% 1.25MPF) composites have the lowest values of thermal insulation, where they have the thermal conductivity (0.912 W/m. °C) and (0.668 W/m. °C), respectively. These results agreed with the mechanical properties results of these two composites, where the pumpkin peels fibers with particle size 2.5 microns that are added with the (1% wt.) and particle size 1.25 microns that are added with the (4 % wt.) act as bridges between the epoxy chains for heat transfer.

(EP/ 2.5MPF) composites have a higher thermal conductivity value than (EP/ 1.25MPF) composites due to the big particle size of pumpkin particles.

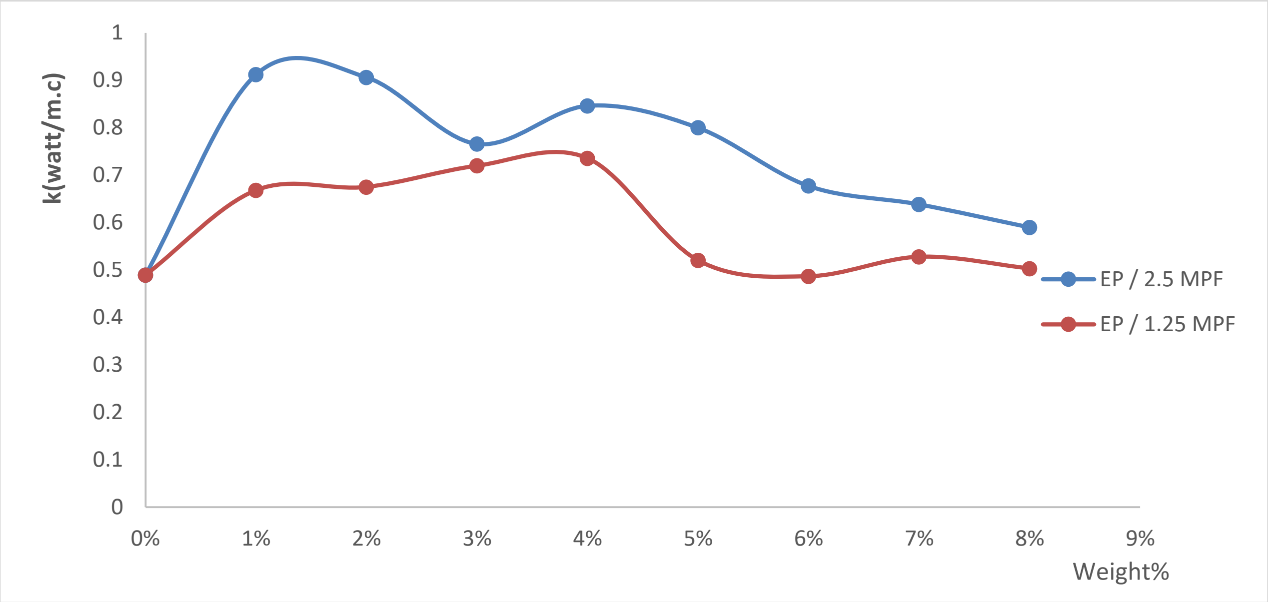

Figure 11. Comparison the thermal conductivity of (EP/2.5MPF) and (EP/1.25MPF) at different weight ratios

4-2-3 Water Diffusion

Figures (12 - 15) show the increase in water diffusion of (EP/ 2.5MPF) and (EP/ 1.25MPF) composites with an increasing in the weight ratios of pumpkin fibers. This is because of the osmotic process, where the water molecules are interring in the small voids and cavities of samples. **Figure (12)** shows that the water diffusion of (EP/2.5MPF) and (EP/ 1.25MPF) composites (for one-week immersion in tap water) have a higher resistance to water diffusion by loading epoxy with(1% wt.) of pumpkin fibers. Still, with the increase in the immersion time to (2 - 4) weeks, the (EP/ 1.25MPF) composite at the small radio of addition (1% wt.), shows higher resistance to water diffusion when compared with the (EP/2.5MPF) composite.

This is because the capillary process increased immersion time due to the diffusion of water molecules into the interface between the pumpkin fibers and epoxy matrix. These results agreed with (Md . Milon et al.) [14].

Figure (15) shows the improvement in resistance to water uptake from (2.654%) for the epoxy to (1.776 %) to (EP/ 1.25MPF) composite at (1% wt.).

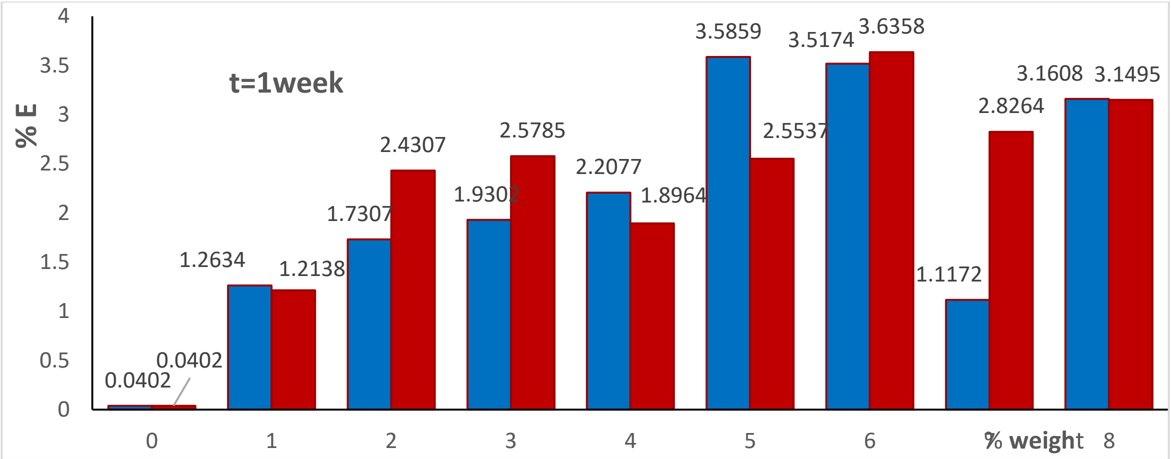

Figure12: Comparison chart of water uptake of (EP / 2.5MPF)and (EP / 1.25MPF) after immersed for (1 week)

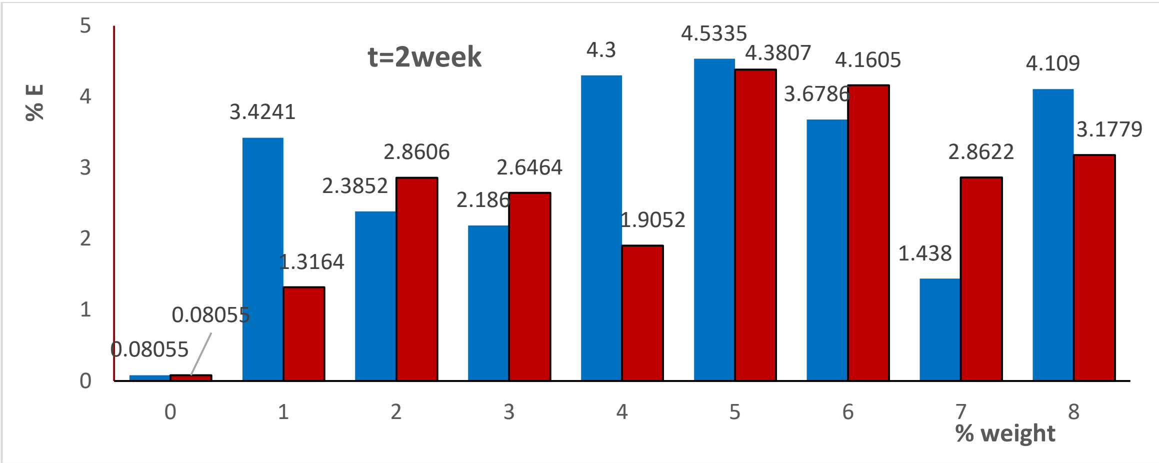

Figure13: Comparison chart of water uptake of (EP / 2.5MPF) and (EP / 1.25MPF) after immersed for (2 weeks)

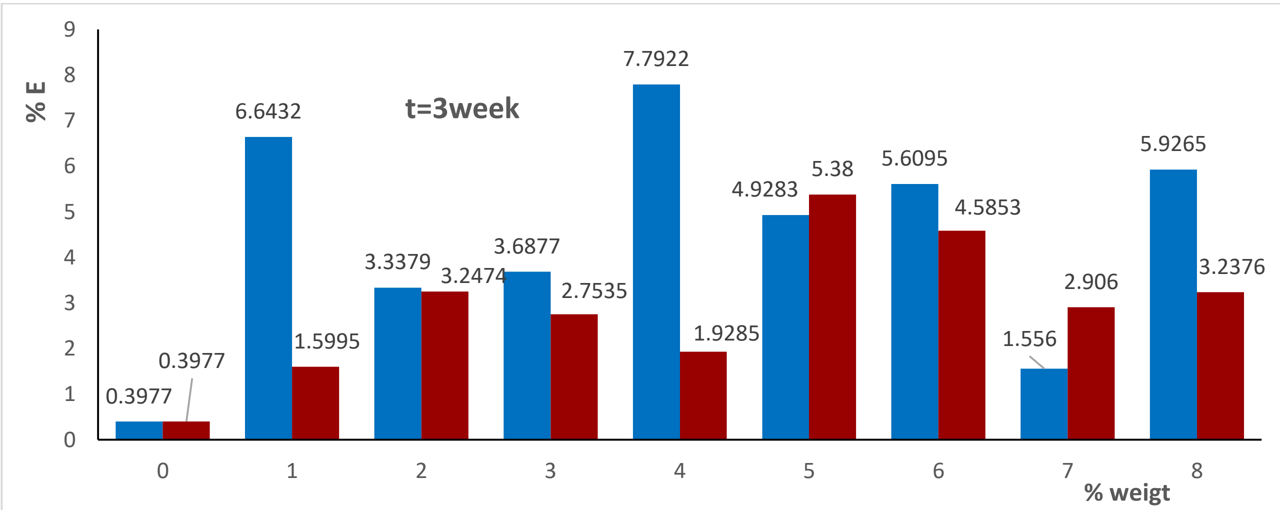

Figure14: Comparison chart of water uptake of (EP / 2.5MPF) and (EP / 1.25MPF) after immersed for (3 weeks)

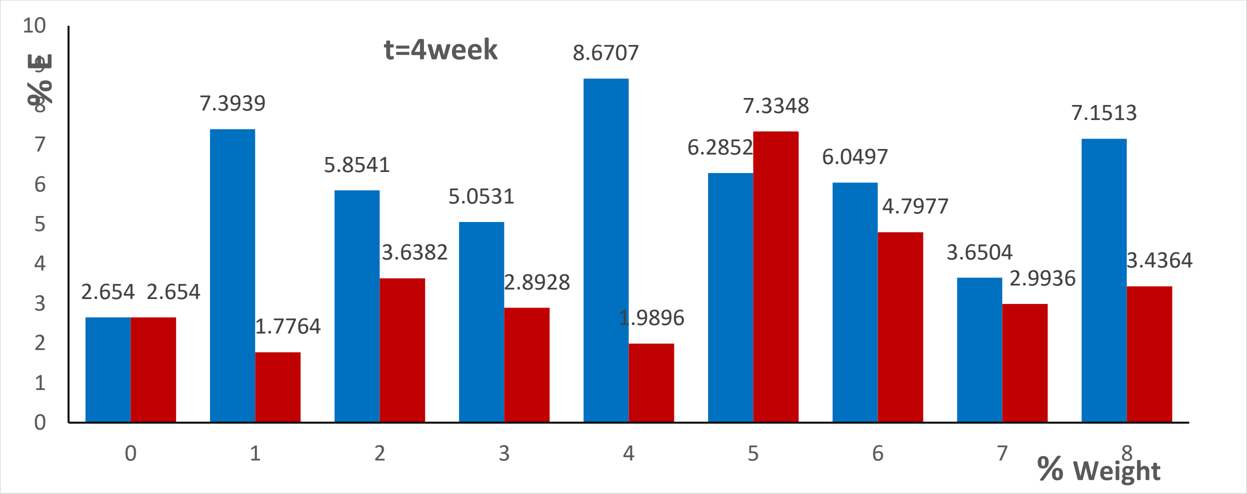

Figure15: Comparison chart of water uptake of (EP / 2.5MPF) and (EP / 1.25MPF) after immersed for (4 weeks)

4-3-Scanning Electron Microscopy SEM

The micrographs of the impact fractured surfaces of (EP / 2.5MPF) and (EP / 1.25MPF) composites with different magnification are shown in **figure (16)**, where the microstructure of (EP / 2.5MPF) shows that the pumpkin fibers are more roughly with compare to the pumpkin fibers in the (EP/1.25MPF) composite.

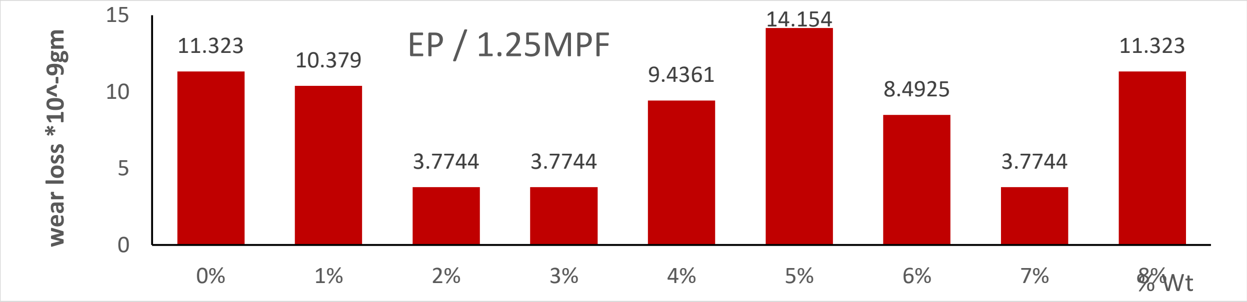

Figure16. SEM images of (EP / 2.5MPF) inspect area a) 50 µm b) 200µm
(EP / 1.25MPF) inspect area c) 50µm d) 200µm

4-4- Energy Dispersion Spectroscopy EDS Test

Figure (17) shows the EDX patterns were obtained for (EP / 2.5MPF) and (EP / 1.25MPF) composites for comparison.

Tables (1, 2) and Figure (18) show that the weight percentages of elemental composition in samples (EP / 2.5MPF) and (EP / 1.25MPF) consist of the elements like Ca and C found at a high rate, and other elements like O and Fe in a lower rate and some traces elements like Si, Mg, and P.

The ratios of all these elements change with changes the particle size of pumpkin fibers, this act on the color of pumpkin fibers, as shown in **Figure (1)**. Some elements were found in very low percentages in (EP / 1.25MPF) composite, like Sb, Na, and H. The elemental composition and the weight fractions of these elements affected the mechanical properties, thermal conductivity, and the color brightness of (EP / 2.5MPF) and (EP / 1.25MPF) composites, as shown in **Figure (19)**, where the sample color change due to the weight ratios of elements and on the weight ratios of powder addition.

This study is considered essential to relate the internal structure of the epoxy and pumpkin fibers (the type and proportion of the chemical elements that are included in it) to the macroscopic shape of the epoxy composites and then the values of the external stresses applied to them.

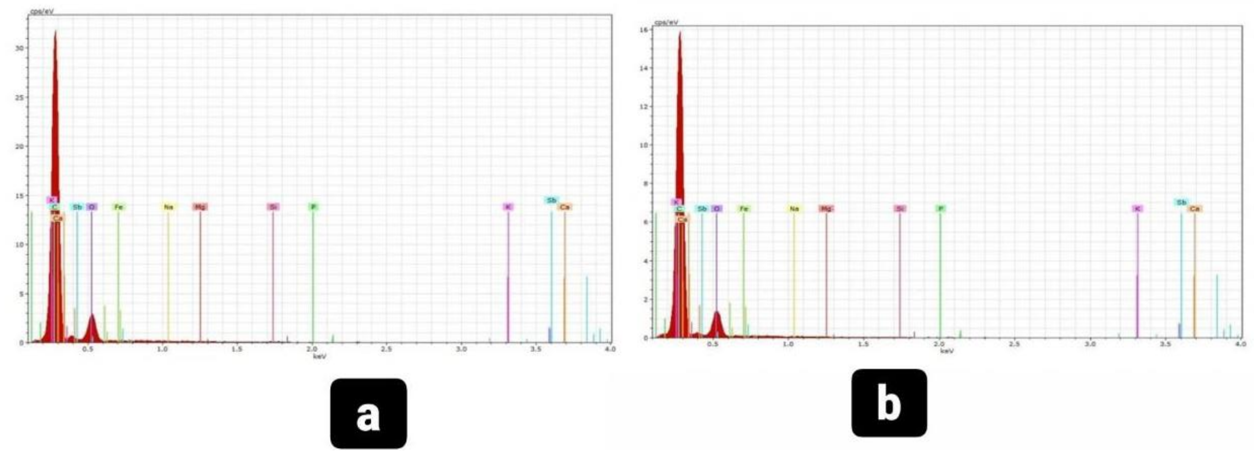

Figure **17.** EDX patterns a) EP / 2.5MPF b) EP / 1.25MPF

Table 1. The elements composition of the Composite EP / 2.5MPF

El	AN	Series	[wt%]
Ca	20	L – Series	70.59
C	6	K – Series	24.54
O	8	K – Series	4.55
Si	14	K – Series	0.20
Fe	26	L – Series	0.10
Mg	12	K – Series	0.01
P	15	K – Series	0.01
H	1	K – Series	0.00
Sb	51	M – Series	0.00
K	19	L – Series	0.00
Na	11	K – Series	0.00

Table 2. The elements composition of the CompositeEP / 1.25MPF

El	AN	Series	[wt %]
Ca	20	L - Series	68.71
C	6	K - Series	25.04
O	8	K - Series	4.67
Si	14	K - Series	0.85
Fe	26	L - Series	0.35
Mg	12	K - Series	0.18
P	15	K - Series	0.10
H	1	K - Series	0.04
Sb	51	M - Series	0.04
K	19	L - Series	0.01
Na	11	K - Series	0.00

El	AN	Series	[wt %]
Ca	20	L - Series	68.71
C	6	K - Series	25.04
O	8	K - Series	4.67
Si	14	K - Series	0.85
Fe	26	L - Series	0.35
Mg	12	K - Series	0.18
P	15	K - Series	0.10
H	1	K - Series	0.04
Sb	51	M - Series	0.04
K	19	L - Series	0.01
Na	11	K - Series	0.00

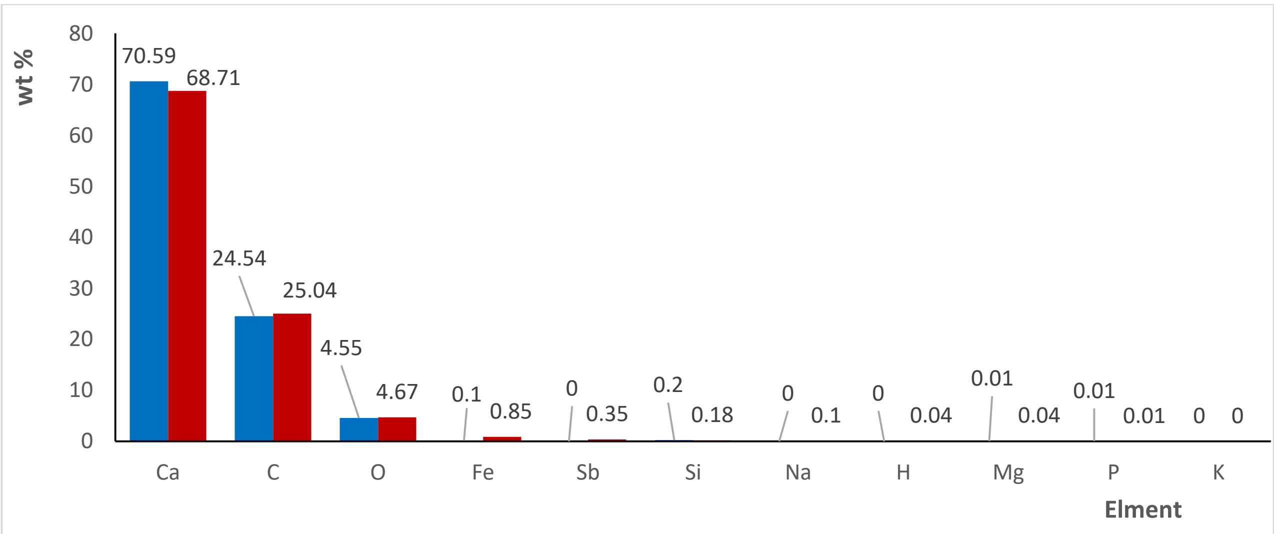

Figure 18. Comparison chart of water uptake of EP / 2.5MPF b) EP / 1.25MPFafter immersed for (4 weeks)

Figure 19. Comparison of EP / 2.5MPF and EP / 1.25MPFwith different weight percentages of loading

To prepare the (EP / MPF) gel coat with high mechanical properties, the epoxy composite with the best proportion of the sizes (2.5 or 1.25) microns pumpkin peel fibers was selected to be the gelcoat, as shown in **Figure(20)**, where the color changed by the change of the pumpkin fibers size and the weight fractions of addition.

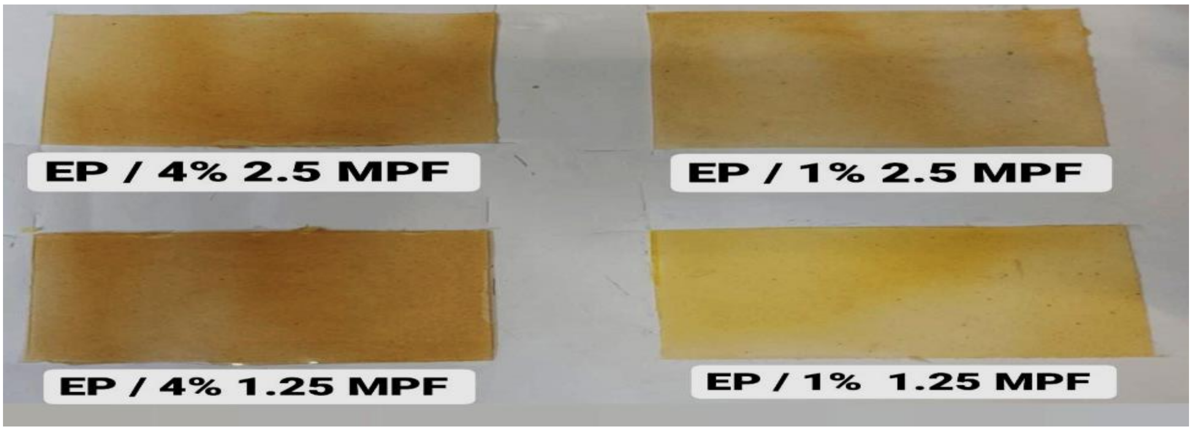

Figure 20. Gel coat a) EP/ 4% (2.5 MPF) b) EP/ 1% (2.5 MPF)c) EP/ 4% (1.25 MPF) d) EP/ 1% (1.25 MPF)

5. Conclusions

The addition of (1 % of 2.5 micro pumpkin fibers) to epoxy will improve its impact strength, flexural strength; wear resistance, and thermal conductivity. By adding the (4 % of 1.25 micro pumpkin fibers) to epoxy, the improvement will take place in its impact strength, flexural strength, wear resistance, and thermal conductivity . The impact strength of (the epoxy/ 2.5 MPF) composite was improved compared with (the epoxy/ 1.25 MPF) composite. The same for the flexural strength, hardness, wear resistance, and thermal conductivity . To get good thermal insulation with good resistance to water uptake (for four weeks of immersion), (epoxy/ 1.25 MPF) composite, at the weight percentage (1%) must be used.

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