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Exploitation of Waste Materials for Repairing Concrete

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Abstract. Epoxy and polymers played a significant role in the world of construction and repair in the past few decades. The major problem in using epoxy for construction repair is its high cost. The current study aims at confronting this problem , and attempting decrease cost by adding waste materials without affecting it's properties,
Window glass and porcelain tile waste were chosen to add to the epoxy at different percentages (10, 20, 30, and 40 %) to create composites that could be used as new repairing materials. The experiment will attempt to find out the suitable percentage of mixing. Such percentage is not used when bonding the concrete to decrease the cost of concrete repairing.
Accordingly, the new composites were tests for compression and bond strength to measure the adhesion strength. The final results showed a general improvement in the properties of the new composite when adding glass and porcelains, yet the porcelains results were much better than glass as filler with epoxy, which achieved the main objective of the current work in finding a developed and better repair material used for cracks and construction with a less cost.

Keyword: WG (waste glass), porcelain tile, epoxy resin, adhesion

1. Introduction

Epoxy is one of the most broadly used engineering thermosetting in electrical, packaging, textiles, electronic and consumer applications since they have exceptional mechanical characteristics. A very wide variety of materials is easily accessed to be used for repairing. Such repairing materials can be of two basic kinds: cementations and resin based [1]. Cementations materials can alternate between the conventional mortars and grouts, and materials of completely enhanced properties which is achieved through the use of admixtures. The use of admixtures can cause high rates of strength gain, greater workability, cohesiveness, and decreasing bleed and shrinkage [1].
Resin-based materials are generally based on epoxy resin and include injection resins, pourable mortars and hand-applied putties. Epoxy resins have a lower modulus of elasticity and higher creep than cementations materials [1]. Therefore, huge efforts have been carried out in order to use epoxy as matrix resins in composites through adding inorganic fillers like alumina [2], fly ash, clays, mica, silica, kaolin etc. [3]
The filler is added to epoxy in order to enhance the properties of composite to become good rapier material. This is achieved through improving compatibility with the structure. That is in terms of increasing modulus of elasticity which becomes non sag, in addition to reducing the cost. The principal advantages of resin-based and filler as repair materials over cementations materials include:

• Very low viscosity for injection into fine cracks

• High bond strength
• High flexibility when required to accommodate movement
• High strength and rate of strength gain
• Resistant to penetration by water, salt, etc.

The aim of the present work is to show the Utilization of polymer composites with waste material as reinforcement and used as repairing material for concrete.

2. Experimental Procedure

2.1. Materials System

2.1.1. *Epoxy*

The matrix material used in the present study was epoxy type EUXIT 50[1] non-pigmented, which consists of two components, liquid epoxy resin and formulated amine hardeners.
It was supplied by SWISSCHEM Company, Switzerland, and the required ratio is 3 resin: 1 hardener.

2.1.2. *Waste Glass (WG)*

The source of waste glass used in this work was window waste featuring Turkish-made glass collected from local window glass vendors. The thickness of the glass was 4 mm. After collection, the WG was cleaned, crushed, and sieved in order to obtain a particle size of 90 microns. Many particle sizes can be used to reinforce epoxy; however, the chosen particle size in this work was 90 microns for both glass and porcelain, which were sieved to obtain this particle size. This particular size was selected to ensure good distribution in the epoxy without precipitation, as coarser particles (larger than 90 microns) may settle in the epoxy due to gravity. The physical properties of crushed WG are shown in Table 1.

2.1.3. *Porcelain powder*

The porcelain powder used in this research was collected from construction waste material remaining on building sites; after they were brought to the lab, samples were crushed using a Jaw crusher then powdered using a HERZOG pulverizing mill HSM, before being sieved using an auto sieve shaker to obtain particles of 90 microns in size. The physical properties of the porcelain are shown in table 1.

Table 1. Physical properties of Waste Glass, Porcelain Powder and Epoxy.

Material	Specific Gravity	Density (Kg/m^3)
WG	2.6	2600
Porcelain	2.4	2400
Epoxy	1.05	1050

2.2. Experimental Work

Composites of the epoxy were synthesized with filler (WG, porcelain powder) particles with 90-micron particle sizes as reinforcement. Different mixes of polymer composite were prepared to study their properties. The first set includes WG at 10, 20, 30, and 40%, while the other set included porcelain powder at 10, 20, 30, and 40%.
The filler was added to the resin and mixed with the resin for 2 to 5 minutes at 27 ˚C until a homogenous mixture was achieved. Then, then the amine hardener was added to the final mix. The

[1] The epoxy type used here is a commercial brand, EUXIT 50, supplied by SWISSCHEM, and the chemical composition cannot thus be identified as it is part of the intellectual property of the company and not available for public consideration.

final mixing process continued for a further 2 minutes at ambient temperature. The composites with different proportions as given in table (2).

Table 2. Polymer composites (WG, porcelain) Mixtures [%]

Specimen NO.	Type of filler	Mixture percentages
1	WG	10:90
2	WG	20:80
3	WG	30:70
4	WG	40:60
5	Porcelain	10:90
6	Porcelain	20:80
7	Porcelain	30:70
8	Porcelain	40:60

When mixing is accomplished, the composites are decanted into molds; after painting the molds with mineral oil to avoid the adhesion of composite, the dimensions of molds are [50 ×50 ×50] mm. The polymer- filler casting is completed in three layers. Every layer is compacted through the use of a vibrating table (Viatest Co. German) for 1-1.5 minutes till the air bubbles disappears from the surface of the casting. The specimens should be de-molded after 24±2 hours from casting, and then complete curing is carried out at room temperature for seven days to ensure full curing until the time of testing.

2.3. Tests

Two kinds of destructive tests to particulate composites are performed; the compressive strength and the bonding strength test.

2.3.1. Density Test

The density of the particulate composites in kg/m^3 were determined according to the standard procedure (ASTM C138) [4] of weighing the specimens and dividing these values (mass in kilograms) by the volumes of the specimens. Table 3 shows the results.

Table 3. Density of particulate composite specimens for glass and porcelain.

	Density (kg/m^3)	
Filler %	Glass	Porcelain
10	1120	1095
20	1244	1164
30	1290	1180
40	1318	1227
epoxy	1050	

2.3.2. Compressive Strength Test

The compression test was usually regulated according to ASTM C109 / C109 M -13 [Using 2 in. or (50 mm) cube Specimens][5]. The specimens were loaded uniaxily by the universal compressive machine (Sercomp, Controls Co. Italy) of 250 KN capocity of the loading rate 2.5 KN per second. The test was carried out for all proportions at the same rate of loading.

2.3.3. Bond Strength test

This test was applied to determine the strength of the bond concrete cylinder specimen through the use of particulate composites as a repairing material according to the ASTM C882/C 882-99 [6]. The bond strength is determined by using the epoxy-filler in order to bond two equivalents portions of a [150 by 75- mm] Portland-cement concrete cylinder, every portion of which has a diagonally cast bonding part at a 30° angle from vertical (see Fig (1)).

Figure 1. Two similar sections of (150 by 75 –mm) PortlIand– cement mortiar cylinder

Wrap the cylindier parts by using tape and plaster to confirm the stability of the parts as well as to prevent mixture of epoxy-filler from blending out of the bonded area. Test procedure starts by mixing the epoxy-filler composites according to the proportions specified in table (1). Mixing it for 3 minutes should be convenient. The bond should keep the mixture of the epoxy-filler injected into the hole at the bond-line and the joint horizontal should be kept at the same time. The texture must be secure with adequate extra masking tape put around the plaster and the wrapped tape. Make sure that the joint is completely filled. The bonded cylinder should be set in the horizontal.
Way for 48 hours. After that all the masking tape must be removed. When the curing process is completed totally, the specimens should be left for 14 days as clarified in fig. (2). Then, test the compression of the specimens in accordance with the method of testing. After the aproppriate curing of the bonding agent, the test is carried out through specifying the compressive strength of bonded cylinders.

Figure 2. Two similar sections of cement mortar after casting at room temp.

2.3.4. Dynamic Modulus of Elasticity (Young's modulus)

In order to confirm the value of the addition of the filler to epoxy to improve the compatibility of the structure, the following calculations are carried out. The ultrasonic velocity of composite was investigated using a double probe through transmission method, according to the British standard BS1881 [7]. The density and ultrasonic velocity were measured, and the dynamic modulus of elasticity (young's modulus) have been calculated from ultrasonic velocity [8] as show in table (2)
Dynamic modulus of elasticity (E) is equal to the product of density (ρ) and square of velocity of sound of the specimen .

$$E = \rho \times V^2 \qquad \text{(1)}$$

Table 4. Average values of ultrasonic parameters of epoxy reinforce with glass and porcelain powder.

Filler Type	Percentage %	Density ρ(kg/m^3)	Velocity V (m/s)	Elasticity 10^9 kg/ms^2
Epoxy	0	1050	1632	2.80
Glass	10	1120	2578	7.44
Glass	20	1244	2646	8.70
Glass	30	1290	2718	9.52
Glass	40	1318	2810	10.40
Porcelain	10	1095	2393	6.27
Porcelain	20	1164	2513	7.35
Porcelain	30	1180	2605	8.07
Porcelain	40	1227	2748	9.26

3. Results & Discussion

After conducting the compression test to ensure that the particulate composite had good adhesion to the concrete surface and acted as a good repairing material, a bonding adhesion test was conducted.

3.1. Density Test

The presence of polymer induces an increase in the density of the composite because of the higher densities of glass and porcelain powder compared to epoxy. The particulate composite density thus varies depending on the amount of fine filler (glass or porcelain), and on how much air was entrapped or purposely retained. Table (2) shows the results of density tests for all proportions of epoxy with glass and porcelain as reinforcing materials**.**

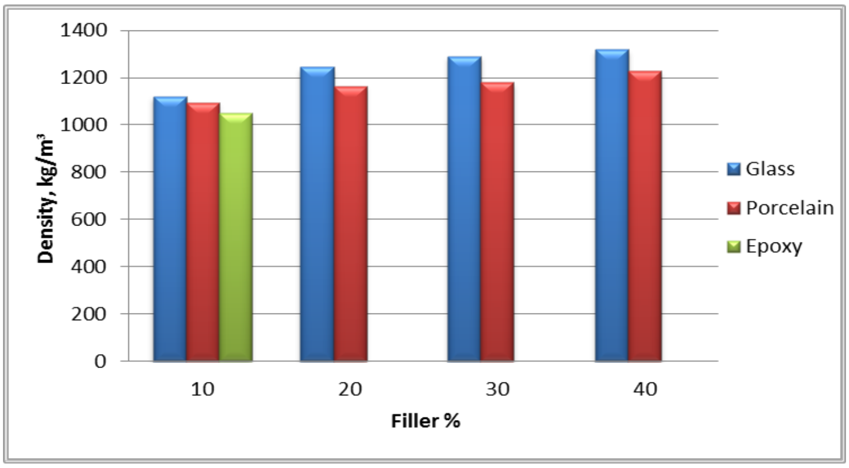


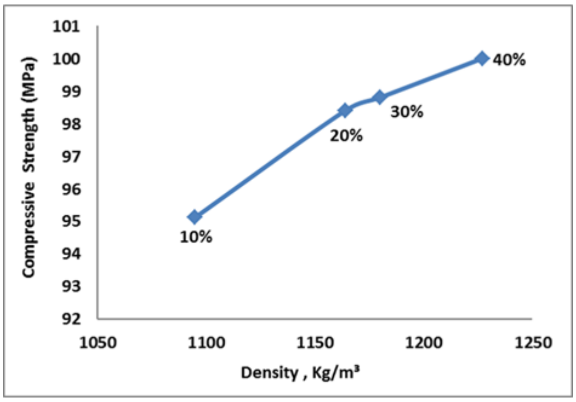
Figure 3. Comparison of density and filler percentage in epoxy.

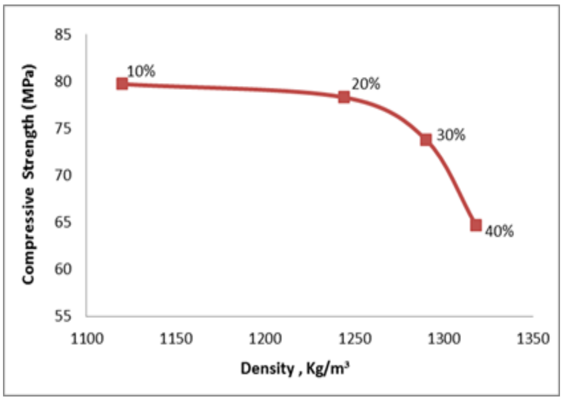
Figure 7 represents a comparison between densities at various filler percentages; the following observations can be concluded from the figure:

- The composite with 40% glass as a reinforcing material has the highest density.
- The density of glass composite is higher than that of porcelain composite at all proportions.
- Adding filler to the epoxy increases the density of epoxy at all ratios.

3.2. Compressive Strength Test

The compressive strength is regarded as one of important characteristics of the particulate-composites. In general, it is one of the basic characteristic values to evaluate the quality of the composite in the national as well as the international codes. Thus, it is important to study whether the changes in the mixture of the composition may influence the early or later or both compressive strengths. The results of compressive strength for all proportions are revealed in fig (3).





(A) (B)

Figure 4. The effect of density on compressive strength for a- porcelain, b- glass composite.

The interpretations that follows are concluded in accordance with the above results:

- The composites of polymer with high porcelain content have higher compressive strength as in 40 % proportion is 100 Mpa , as a result of the good bonding as well as good strength.
- The composite of polymer that contains glass powder showed a reduction in compressive strength, as a result of the poor bond between filler particles and polymer. Resulting from smooth texture of glass powder, and its relatively low resistance to fracture [9].
- The percentages with 20% and 30% porcelain powder gives a moderate values according to fig (3).

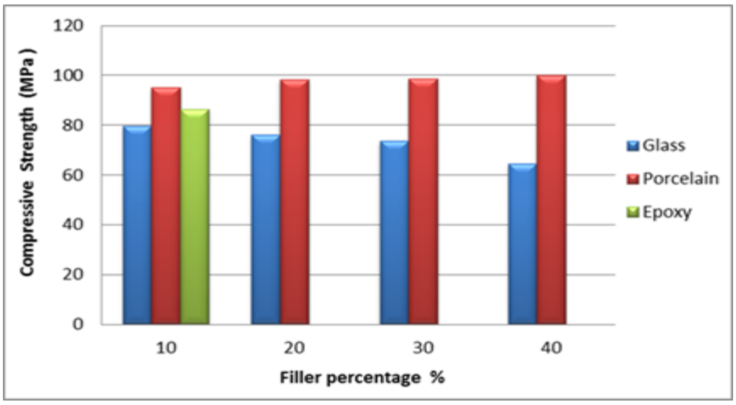


Figure 5. Comparison among the compressive strength of various proportions of the composites and epoxy while not reinforcement

The comparison diagrams show the following observations:

- The reinforce with porcelain is better compressive strength than that reinforcing with glass.
- Glass powder with 40% ratio is the lowest value.

Figure (4) shows the comparison between compressive strength and filler content; it can be observed that with low percent of filler the compressive strength increases. This is due to high degree of adhesion between the polymer molecules and filler particles, the enhanced compressive strength properties of the composites with porcelain over that of the matrix (epoxy) may be due to the stiff nature of the filler, while in high percent of filler (glass) the compressive strength decreases, This is due to the filler particles that extended the distances between the epoxy molecules, i.e. breaking the intermolecular forces between these molecules.

3.3. The Bond Strength Test

When estimating the bond strength of the resin bonding system through the division of the load carried by the specimen at failure and by the area of the bonded surface, it is found that the area of the elliptical bonding surface of the test cylinders stated in the present test method is (9116 mm2)[6].

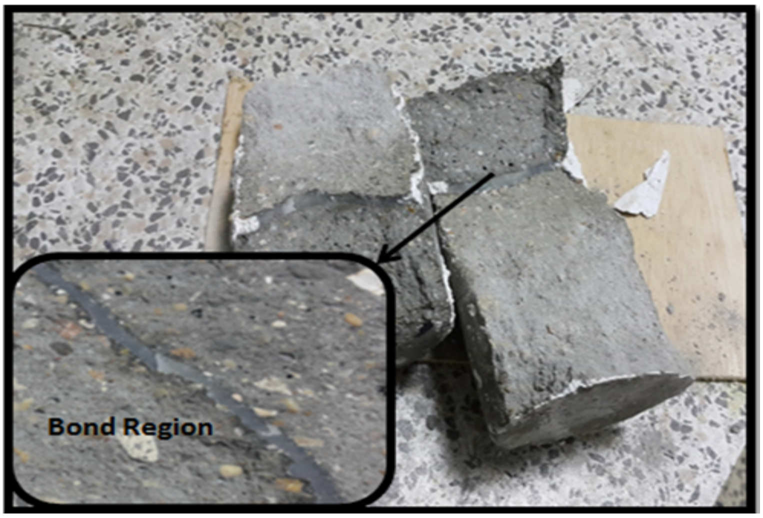
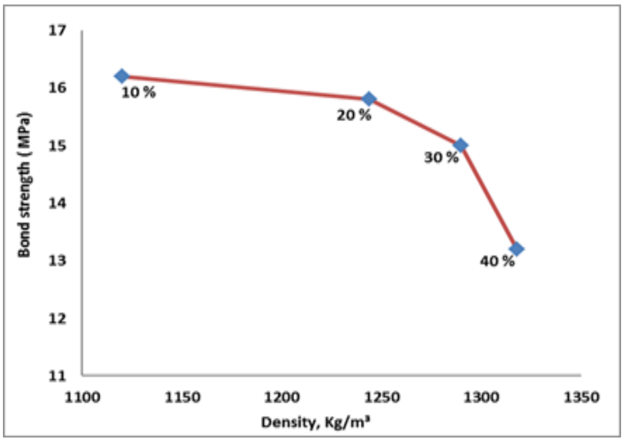
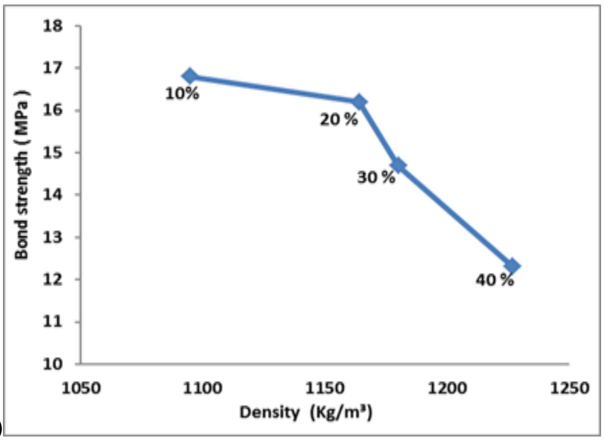


Figure 6. The bond strength of polymer composites after fractur takeing place within the main cylinder whereas the bond region is not affected.

The results show the failure has taken place in concrete cohesion failure (CCF) but did not happen in epoxy adhesive composite as shown in figure (5), because there are adhesion forces between concrete and epoxy adhesive mixture and Adhesive cohesion forces are stronger than concrete cohesion forces, resulting from mechanical interlocking theory and adsorption theory between concrete and epoxy adhesive mixture; Additionally the electrostatic attraction theory between adhesive chains is very good, The bond depends on adsorption theory, adhesive molecules adsorption inside concrete surface and formation bonds between surface for concrete – epoxy adhesive mixture of good adhesion force . For that the failure happened in concrete zone [10][11]. This indicates the use of suitable repairing material and good bond strength as revealed in fig (5), and the results are displayed in fig (6).



(a)



(b)

Figure 7. The effect of density on bond strength for a- Glass composites, b- Porcelain composite.

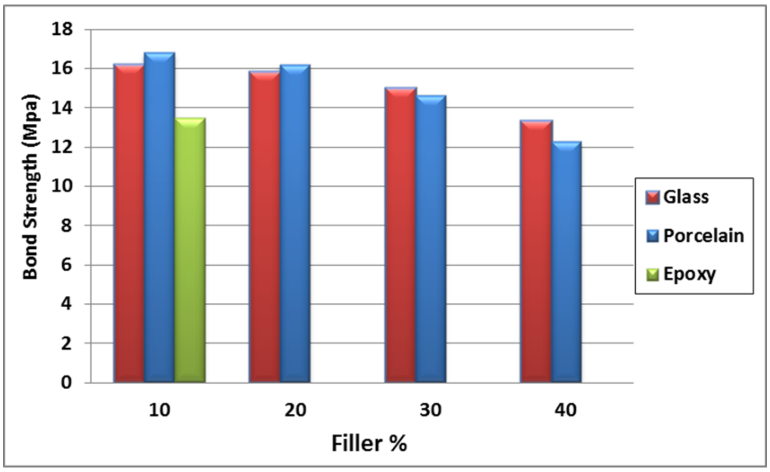


Figure 8. Comparison among the bonding strength of various proportions of the composites & epoxy without reinforcing.

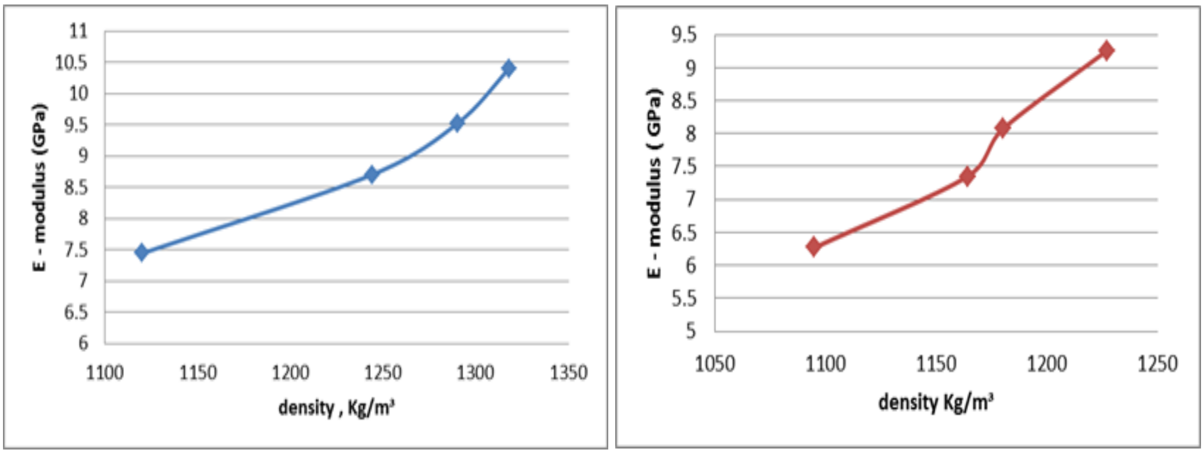
The following observations can be concluded from the figures (7 and 8):

- The percentages of (30, 20 % glass) displayed moderate values, that is as a result of low density as well as low compacting among particles.
- The epoxy-porcelain composites of 10% percentage displayed a higher bonding strength. Such behavior is resulted from the effective bonding as well as good strength.

- It is worth noting that all the percentages shown here are more than 10 (MPa). Such results, according to the table of Physical Requirements of Bonding System stated in the ASTM C881, are considered good repairing material [5].

3.4. Dynamic modulus of elasticity (Young's modulus)

Figure (9 and 10) explains the effect of the filler content on the composites that have modulus of elasticity. As expected, the E-modulus of the composites markedly improved with addition of porcelain and glass content. This improvement because of the glass and porcelain particle which is inherently stiff. Thus, it influences the stiffness of composite as a whole [12].



(A) (B)

Figure 9. The effect of density on E – modulus for A- Glass composites, B- Porcelain composite.

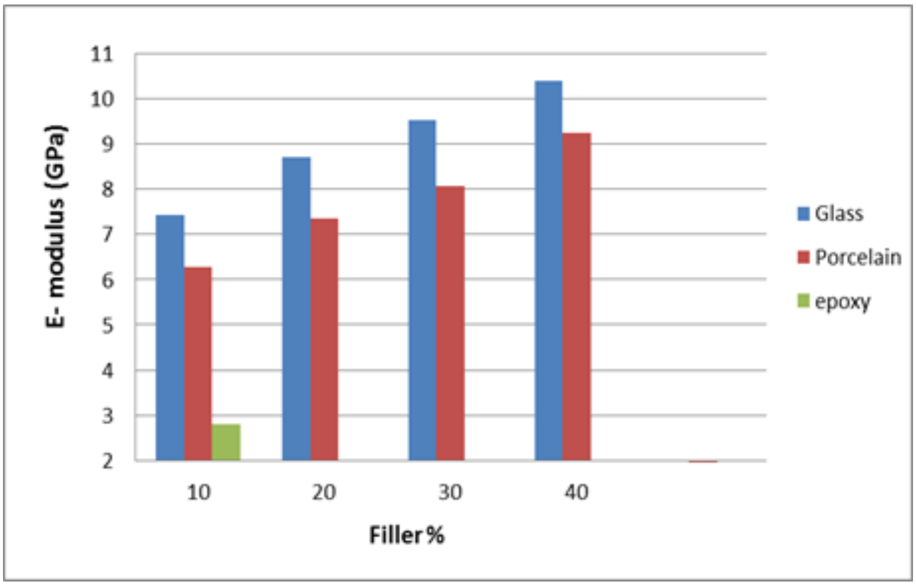


Figure 10. Comparison between modulus of elasticity of various proportions of composites and epoxy without reinforcing.

4. Conclusions

The following observations can be drawn from the test results:

1) The final results showed a general improvement in the adhesion properties of composites when adding both glass and porcelain; nevertheless, porcelain results were much better than those seen with glass as filler with epoxy. This result achieved the main objective of the

current work in terms of developing a better low-cost repairing material for concrete substrates to be used for repair cracks in construction applications.

2) The strength and adhesion are regarded as crucial elements in the bonding and portability of repairs. Furthermore, the addition of filler to the epoxy will improve the bonding strength, when epoxy played a role in reducing the brittle nature of filler.

3) The composite with porcelain particles at a ratio of 10 % gave the best results for the bonding test (16.8 MPa), and the failure took place in the concrete substrate due to a good interface between the epoxy and filler particles

4) For glass composites, the highest bonding strength (16.2 MPa) was also for a 10% percentage at room temperature.

5) The composite with porcelain particles at a ratio of 40% gave the best results in the compression test (100 MPa). For glass composites, the best compression result (85 MPa) at the 10% percentage.

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