ISSN: 2617-2070(Print) ; 2617-2070 (Online)
Journal of Advanced Sciences and Engineering Technologies
Available online at: http://www.isnra.com/ojs/index.php/JASET/



Journal of Advanced Sciences and Eng. Technologies
JASET

# Improve the bonding material properties used to strengthen concrete beams

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***Keywords***
Adhesive material
Brick powder
Carbon fiber
Concrete beams
Glass powder and porcelain powder

***ARTICLE INFO***

***Article history:***
Received 01 November 2018
Accepted 15 November 2018
Available online 01 December 2018

**DOI:** https://doi.org/10.32441/jaset.v1i3.181



**A B S T R A C T**

The subject of the research deals with the study of the effect of recycling and addition of some cheap and locally available materials on the properties of the adhesive material (Epoxy) used to strengthen concrete beams. Where the study included the addition of glass powder, brick powder and porcelain powder to the adhesive material and with different ratios of the weight of the adhesive material (0, 0.25, 0.5, 0.75, 1 and 1.25). After conducting laboratory tests proved the results of the study that the best types of additions are porcelain powder and the best ratio of adding was about ( 0.25). This addition to the adhesive material in this ratio led to improve the reaction temperature at mixing the parts of the adhesive material where decreased by 15.56%, as well as improved workability through lower flow of the consistency of adhesive material about 7.89%, as increased compressive strength by 13.33% and improved the modulus of elasticity by11% only, but The modulus of rupture decreased by 7.04% and the strength to high temperatures (limit to 250C°) decreased by 29.17%. The new bonding material was tested to strengthen the CFRP concrete beams. The results showed that the compressive strength of these beams increased by 70.97% compared to the normal non-reinforced beams and the strength of the Toughness beams increased by 61.87%.

## Introduction

The efficiency of concrete parts strengthening by carbon fiber depends on the proper bonding between it and the concrete through the adhesive material that is used . Therefore , the need to improve the properties of the adhesive material is very important ( Gao et al., 2004 ) . There are many types of adhesive material, and that all types that is used divided into two parts, the first part is a resin material and the second part is a hardener material. These materials are generally expensive because their use in large amount leads to a high cost of maintenance and have several disadvantages. The most important one is that the temperature of the interaction between the parts of the material when mixed together is high, which leads to hardening the material quickly when it is mixed in large amounts so that small amounts of material are mixed to control the reaction temperature (Täljsten and Blanksvärd , 2007; Abdulla, 2016) .

## Literature review

There are many studies on the adhesive material which can be summarized as follows:

Janabi ( Janabi , 1994 ) has Studied mechanical properties for epoxy strengthen with fibers palm and in different proportions (16% , 18%). The palm fibers used in this study are natural fibers represented by the inner part of the palm (the heart of the palm). Several sample were worked and exposed to degrees of different heat. Researcher concluded that durability of epoxy is increased by increasing of strengthening by fiber and by increasing of the temperature to a certain temperature(Tg) . The best of strengthen ratio for the material is 18% .

## Works Cited

**There are no sources in the current document.**

Hisham and others (Hisham et al. 1999) calculates modulus of elasticity and modulus of rupture for epoxy of strengthened with three cases where it was strengthened once with copper wires, and once other with steel wires separately as well as the strengthening of hybrid both types together ( the copper wires and the steel wires evenly ). The ratio of addition was fixed 8% for all these materials, where it studied the properties of this strengthening for epoxy material at degrees of different heat (0, 28, 40, 50)C° and compare results with normal epoxy material . It was concluded and all types of strengthened epoxy with wires that modulus of elasticity is increasing with strengthen by wires and less with an increase temperature. The modulus of rupture increases with strengthen by wires as well with an increase temperature except when approaching the degree of glass transition (Tg) where the modulus of rupture is lower.

Kereem ( Kereem , 2002) has studied the mechanical properties of strengthened epoxy by powder from nickel. Powder is used with different sizes and ratios, where is found that the modulus of elasticity and compressive strength are increasing with increase the ratio and size of particles of nickel powder added .

Camata and others ( Camata et al., 2007 ) have studied the effect of exposing the concrete sample of strengthening by types of epoxy and strips of carbon fiber to high heat cycles up to 100 Cº . The study proved that all types of epoxy which used has affected with high heat cycles.

Osman Asi ( Osman Asi , 2008 ) has studied the effect of alumina powder addition by 10% of the weight of the bonding material on mechanical properties for epoxy strengthen by glass fiber . The researcher concluded that flexural strength and the modulus of elasticity increasing by 33% and 78% respectively at alumina powder addition comparison with epoxy strengthen by glass fiber and not strengthen with alumina powder .

Kelmer ( Klamer et al., 2008) has studied the effect of temperature on the reinforced concrete beams strengthening by epoxy and carbon fiber. Test results showed that the load and type failure of beams were not affected at temperature 50Cº compared with room temperature , while the effect began at a temperature 70Cº where the type of failure of a beam from a failure in concrete to a complete failure in the epoxy.

Blanksvärd ( Blanksvärd , 2009 ) has used a new adhesive material instead of epoxy consisting of (polymer - mortar- plasticizers- fibers), and experience has proved that the new adhesive is effective to adhesive the carbon fiber, but this material is expensive and difficult to use because of the difficulty of controlling the mixing ratios of many of its components and can nevertheless use this adhesive to control cracks in the concrete.

Balqis and others (Balqis et al., 2009 ) have studied the effect of ultraviolet radiation on some mechanical properties of the strengthened epoxy in four different cases and by 30%. First case by glass fiber and aluminum powder , second case by glass fiber and silica powder, third case aluminum powder only, and finally silica powder only. The sample exposure to radiation to intervals (15 , 50 , 100) hours , and concluded that the best of strengthening cases for epoxy are first and second cases, where are increased compressive strength and modulus of elasticity and resistance to impact and all exposure to the rays of ultraviolet conditions.

Fonseca and others (Cabral-Fonseca et al., 2011 ) have studied the effect of environmental conditions on three different types of epoxy used in the strengthening and rehabilitation of concrete structures. Where are worked models and immersed in sea and alkaline solutions for 18 month at different temperatures between ( 40-60 ) C°. Then tested the mechanical properties and weight loss of samples. The study has proved that epoxy is greatly influenced in environmental conditions such as sea water and alkaline solutions.

Mohamed (Mohammed, 2011) studied mechanical properties for adhesive material ( epoxy ) strengthen by copper powder with different ratios, and concluded that an increase ratio copper powder to epoxy increased from flexibility, stiffness, impact strength and reduce the strength of fracture and friction of epoxy, and the best ratio of addition is used 15% , which has improved from mechanical characteristics for epoxy .

Abdulaziz ( Abdulaziz , 2013 ) has added a steel powder and silicon carbide with different ratio from these materials (30%, 20%, 10%) to adhesive material (epoxy) in addition to using metal net, polymer net and glass fibers, where is bonded with metal samples from steel , copper and aluminum . This process led to increase in the strength of the adhesive for epoxy after use of these materials. This study includes the effect of the addition of different strengthening materials on shear stress, and included change of the addition of the strengthening material with different ratios, and the effect of this change on resistance shear for bond layer . Done measure strength of shear for models and noted improved in shear strength with contrast in the ratio of improvement of shear resistance with different of additive materials and type metal, and it was the improvement ratio great at shear strength for models of copper adhesive by epoxy added for its steel powder by 10% as a ratio of the weight of the bonding material.

Khaled and others (Khaled et al., 2014 ) have studied the strengthening of the adhesive material (epoxy) by powder of magnesium oxide ( Mgo ) and with different ratio of epoxy weight ( 5%, 10%, 15%, 20%, 25% ) . Where are tested the modulus of elasticity and hardness of this strengthening. The results are showed that the modulus of elasticity increases with increase of powder , the hardness is increased by a nonlinear relationship with increased powder of magnesium oxide .

Wadad (Wadad , 2016 ) studied the impact strength and the water absorption of the epoxy material strengthen and reinforced with eggs shells powders for chicken and different ratios (1%, 2%, 3%, 4%) . It has been found that the addition of the eggs shells powder by (1%) provides high resistance to impact and water absorption .

Abdallah and others (Abdulla, AI et al., 2016) have studied improvement the properties of bonding material (Epoxy) where their studies included studying the mechanical properties resulting from the addition of fine sand to the bonding material with different ratios (0.25, 0.5, 1, 1.25, 1.5) of the weight of this adhesive material. The results of the tests are showed that this addition increased compressive strength, modulus of rupture ,fire resistance, toughness and stiffness of this material also reduced the temperature of the reaction resulting from mixing of adhesive material parts, and also improved the workability of this material well. It has also greatly increased its toughness and stiffness and ductility for reinforced concrete beams strengthening by carbon fiber (CFRP). It was best ratio of sand is added (1), thus this addition contributed in reducing the cost of the bonding material .

### *Objective of the study*

The current study aims at obtaining an economic bonding material with improved specifications by adding one or more inexpensive local materials to the bonding material, which will lead to reduction in its cost and improve some of its properties. The materials that will be added are glass powder, brick powder and porcelain powder . It will conduct all the necessary tests on the improved adhesive material to sure their properties and can be used in such type of curing.

## Practical program

The practical program of this research will be divided into two parts:

### *The first part : Find the optimal addition ratio*

This part includes the addition of powders of the three materials and different ratios of the weight of the bonding material (0, 0.25, 0.5, 0.75, 1, 1.25) separately to adhesive material , which consists of two parts , part (A) and part (B) which is mixing by 1:3 The addition will be to one of these two parts A or B before the process of mixing with each other to ensure of maintaining on good workability, and after conducting the necessary tests the best of these three types will be selected with the best ratio gives the best results.

## Materials

At this part of the study the following materials were used:

### *Adhesive Material*

The adhesive material of high adhesion is used in this research and known as Sikadur

®-31, contains medium viscosity materials, Its density is limited (1.65kg/L ).This material is divided to two parts as mentioned earlier, the properties of the adhesive material are shown in table (1).

**Table 1. Properties of the bonding material**

| Properties | Description |
|---|---|
| color | A:white, B:Black, A+B: light gray |
| Density | 1.65 kg/l (parts A+B mixed) (at +20°C) |
| Mixing | 1:3 (A:B) by weight or volume |
| Pot life | +10°C :120 min., +20°C :60 min., +30°C :25 min. |
| Application temp. | +10°C to +30°C |

## Additives

These materials include glass powder, brick powder and porcelain powder, are mulling these materials and make the process of sieve analysis her and pass sieve size 300 µm to 75 µm, and the remaining is taken on a sieve 75 µm . And then use these materials after being washed well and dried before use. Separately each material is added by (0.25, 0.5, 0.75, 1, 1.25) of the weight of the adhesive (see Fig. 1).

**Figure 1 Epoxy with powders**

**First part tests**

At this part, the following tests have performed:

## Mixing temperature

The heat between two parts of adhesive material always very high through mixing, therefore not possible to mix a large amount from epoxy because the high heat will lead to rapid hardening, expansion of epoxy and losses of strength (Abdulla, 2016). The addition of glass powder, brick powder and porcelain to the epoxy led to reduce the heat through of the reaction, thus becoming with possible mixed with a large amount. The heat measured before and after addition of powders to epoxy by thermometer.

## Consistency of adhesive material

To ensure the coherence of the improved bonding material which expresses its flow which can be calculated according to ( ASTM C 230 and ASTM C 1437) which originally explain the mechanism of calculating the flow of a mortar cement, however, was used to calculate the flow test of the bonding material by several researchers (Abdulla, AI et al., 2016) . Where the examination was done through fill the cone container in mixture on the disk after the container was lifted and then the disk is reduced 25 times during 15sec was then measure the diameter of the flow of the mixture for each ratio added. Fig. 2 explain this examination.

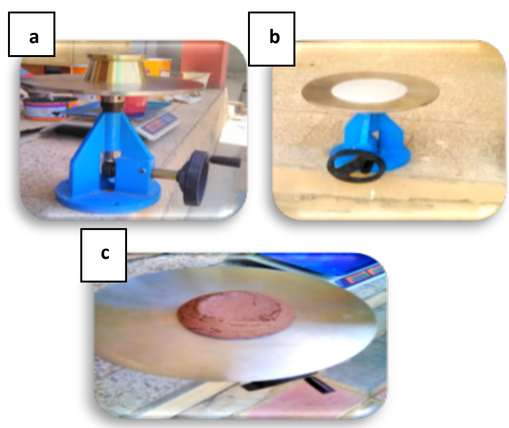



**Figure 2** (a) Flow table. (b) Mixture before adding powders.(c) Mixture after adding powders.

## Mechanical properties

**A.** Casting cubes (40x40x40 mm) and prisms (40x40x160 mm) from adhesive material after adding the powders with different ratios. The models were examined at the age of 3, 7 and 28 days of the compressive strength test for cubes according to the ASTM C109 (ASTMC109, 2004), and the modulus of rupture test for prisms according to the ASTM C 348 (ASTM-C348, 2004). The prisms were placed under a concentrated load (One Point Load) the distance between the supports 100mm, as shown in Fig. 3.

**B.** To investigate from effect of temperature on the mechanical properties of cubes placed in the oven for three hours and at different temperatures where that the compressive strength of the cubes that resulted from the examination of the models after removing from the oven reverse the effect of temperature on these characteristics, the models placed at different temperatures starting from (25 C° to 250 C°) and increase the temperature by 10C° every minute and eventually the temperature stabilizes for an hour to ensure a uniform distribution of temperature (Abdulla, AI et al., 2016).

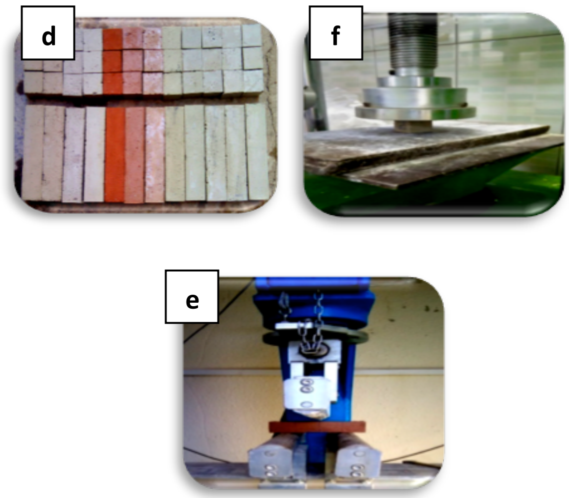



**Figure 3** (d) Models of cubes and prisms.
(e) Prisms test.
(f) Cubes test.

## The second part : The experience of improved bonding material

The first part ends with obtain of a new improved bonding material resulting from addition of the best types of three powders with the best ratio is added to the original bonding material. The second part begins with experiment this the improved bonding material through its use in strengthening reinforced concrete beams and strengthen its by carbon fibers to verify their effectiveness in bonding carbon fiber with beams. Carbon fiber was used of type SikaWrap - 300C as it are available in local markets.

The reinforced concrete beams are designed with a section (150 x 150 mm) and length (1000 mm) . It was reinforced 2Ø6mm at the top and 3Ø6mm at the bottom and Ø6mm @ 60mm to shear force. Yield stress of reinforcing steel (672)Mpa (Longitudinal reinforcement and shear reinforcement within limits ACI-Code), where are casting nine beams for three different cases represent the first of which a normal model without any strengthening symbolizes (A), and the second represents a

Model after strengthened by CFRP with using the normal bonding material symbolizes (E), while the third model after strengthened by CFRP with using the improved bonding material and symbolizing it (P) with three beams for each model. All models tested under concentrated load (One Point Load) to know the type of failure and bearing capacity. Concrete mix used in casting beams is designed according to (ACI-Code) and their properties are shown in the table 2 .

**Table 2. Properties of concrete mixing**

| Properties | Test results |
|---|---|
| Compressive strength (Mpa) | 30.4 |
| Splitting tensile strength (Mpa) | 3.14 |
| Flexural strength (Mpa) | 10.027 |
| Slump (mm) | 85 |

* Results calculated for the rate of three models per property.

## Results and discussion

### *Mixing temperature*

The tests proved that the addition of these three powders reduces the reaction temperature directly, with increase the ratio of the addition of powders decrease in temperature. Fig. 4 shows clearly the effect of adding powders on the heat of the reaction and it is clear that the drop in temperature is more acceptability at addition ratio 0.25 for all three powders.

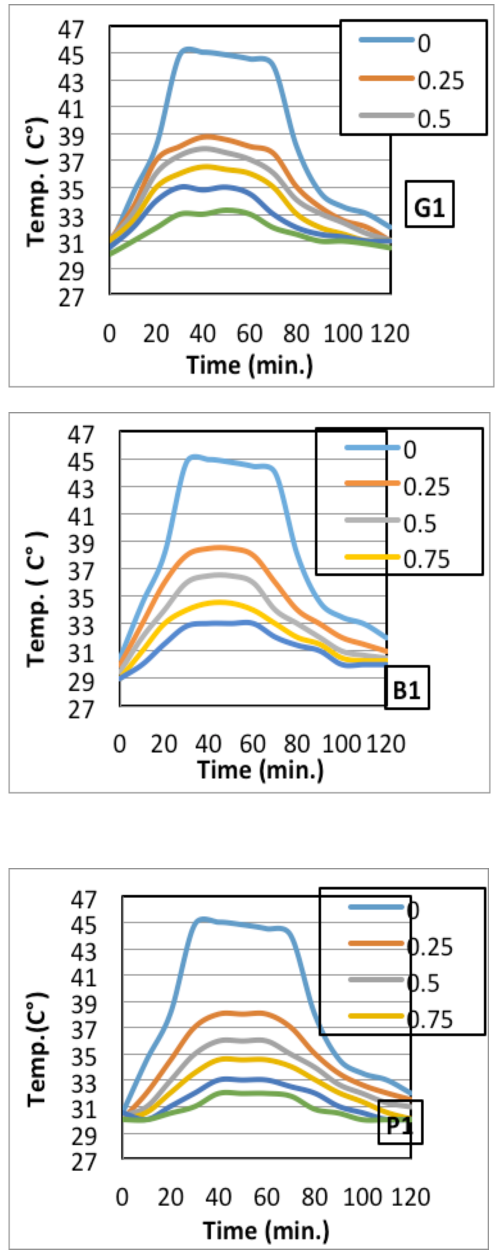



**Figure 4** (G1) temperature after mixing with powder glass. (B1) temperature after mixing with powder and bricks

(P1) temperature after mixing with porcelain powder

## Consistency of adhesive material

The flow of the mixture decreases with the increase of the addition ratio of all the powders as shown in table 3. It has been note that the ratio (0.25) has given of decreasing ratio more acceptability of the flow of the mixture of the other ratios also it has been note that the addition of brick powder leads to a greatly decrease in the flow of the mixture to the point can not be added with the ratio 1.25, leading to weakness of workability is very large.

**Table 3. The mixing ratios of the adhesive and the flow values of the mixture**

| Mix ratio | Glass powder flow% | Brick powder flow% | Porcelain powder flow % |
|---|---|---|---|
| 0 | 190 | 190 | 190 |
| 0.25 | 150 | 125 | 175 |
| 0.5 | 120 | 100 | 142 |
| 0.75 | 89 | 83 | 100 |
| 1 | 75 | 75 | 75 |
| 1.25 | 65 | | 65 |

## Mechanical properties

***Compressive strength*** : Fig. 5 shows the compressive strength of the bonding material cubes of all mixing ratios and all powders and different ages of curing. The results showed increased compressive strength when adding porcelain powder to the limits 13.33% when mixing ratio (0.25) in comparison to the reference mixture. This increase gradually decreases with increase of the addition ratio, while the compressive strength decreased by 6.67% and 10.94% when adding glass powder and brick powder respectively at (0.25) mixing ratio, while the decrease was very large at other mixing ratios.

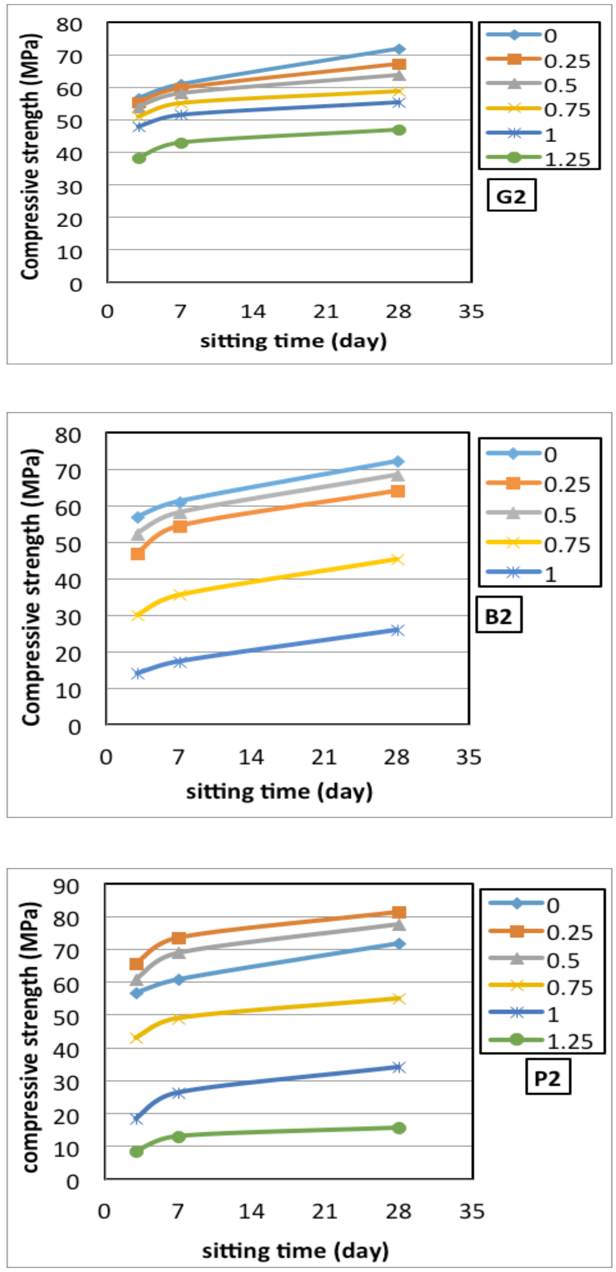
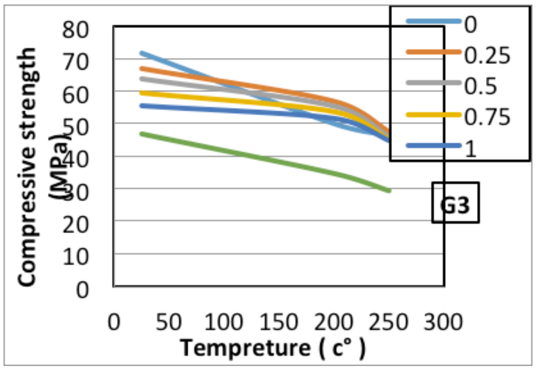
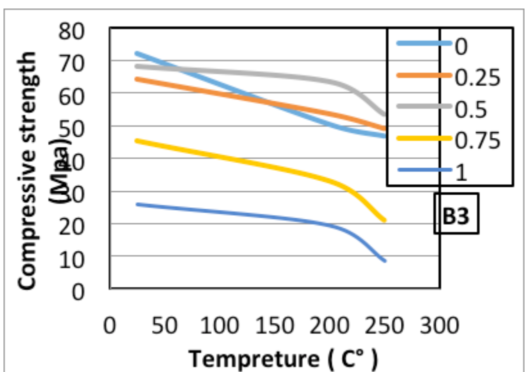
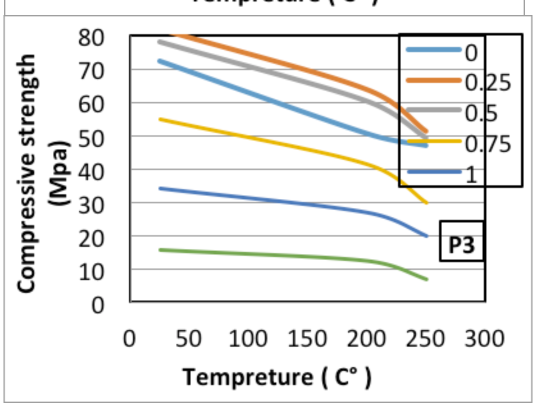


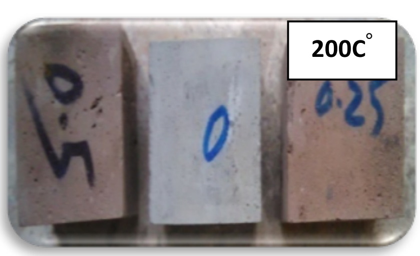

**Figure 5:** (G2, B2, P2) Compressive strength of the cubes of different ages for ratios of addition glass, brick and porcelain powders respectively

Fig. 6 shows compressive strength due to increased temperature, where all proportions of powders have lost their resistance at 200C º. At the temperature 250C º there were cracks in the models in addition to changing the color of the surface at all mixing ratios, which led to a drop in resistance more than it was at 200C º but the lowest of reduced ratio was to porcelain powder where was up 11.8% from the reference mixture while decreased by 20.69% and 25.69% for each of the glass powder and brick powder at the mixing ratio of 0.25 and increased of reduced ratios increasing mixing ratios.



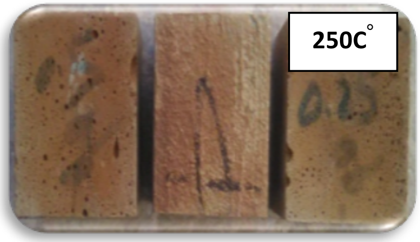
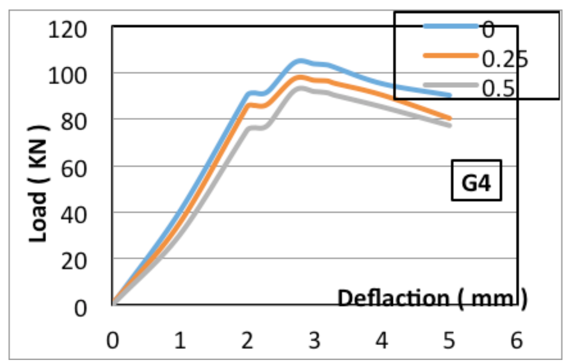
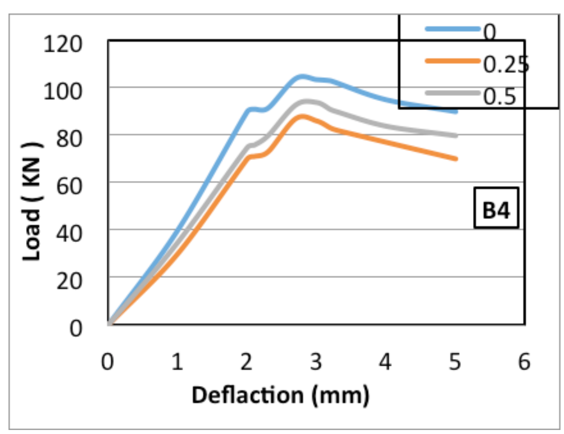
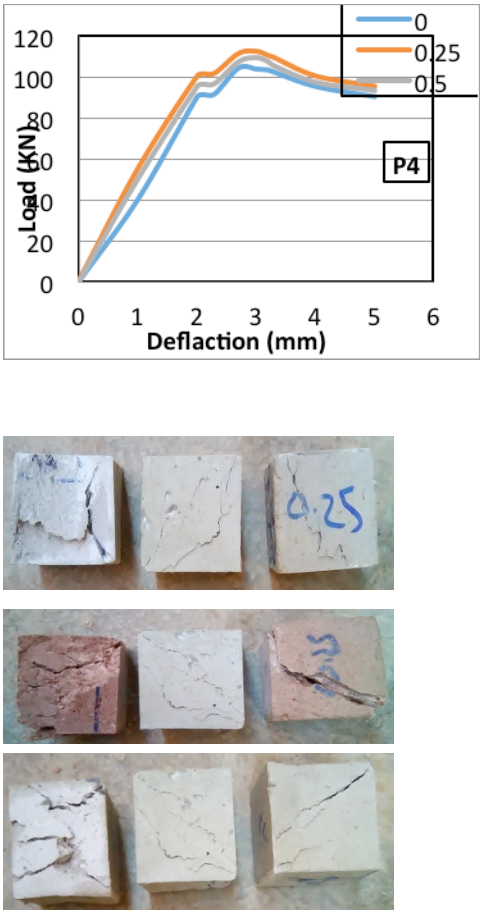




**Figure 6:** (G3, B3, P3) Effect of temperature on compressive strength of glass powder additives, brick powder and porcelain powder respectively to the bonding material. (g) Cubes after exposure to heat

**Modulus of elasticity:** Fig.7 shows the relationship between load-deflection for cubes of the adhesive material. The value of the modulus of elasticity is increased when adding porcelain powder up to 11% of the reference mixture with mixing ratio 0.25, while reduced value when adding glass powder and brick powder up to 6.5% and 22.2% respectively with mixing ratio 0.25, and increases the value of decrease by increasing the mixing ratio.






(h)

**Figure 7:** (G4, B4, P4) Load-deflection relationship for cubes add glass powder ,brick powder and porcelain powder to the adhesive material respectively. (h)Cubes after failure.

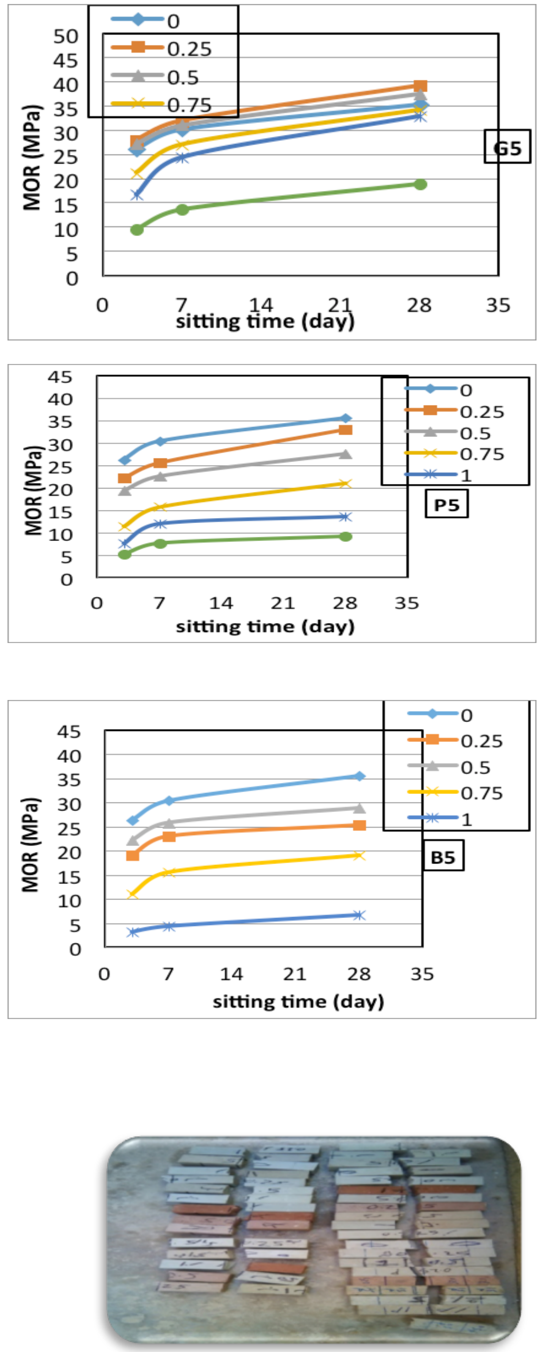



**Figure 8**:(G5, B5, P5) Modulus of rupture for prisms for different ages for the addition of glass powder, brick powder and porcelain powder respectively. (i)Prisms after fracture

**Modulus of rupture** Fig. 8 shows the relationship between modulus of rupture for the addition ratios of all powders for different ages, where the modulus of rupture for glass powder increased by 10.54% at adding ratio 0.25 from the reference mixture, while the value decreased when adding brick powder and porcelain powder by 28.73% and 7% respectively at the ratio of 0.25.

The previous tests show that the best addition ratio led to improve most of the properties of the bonding material is 0.25 and from table (4), which shows the summary of the results of the tests conducted on the bonding material and all the powders at the ratio of adding 0.25 . The best type of the three powders is porcelain powder. So that the improved bonding material that resulted from the addition of 0.25 porcelain powder to the original bonding material will be tested and used to strengthen reinforced concrete beams .

| Powder additive | Percentage of reaction temperature | Percentage of the consistency of the bonding material | Percentage of compressive strength | Percentage of the effect of temperature on compressive strength | Percentage of modulus of rupture | Percentage of modulus of elasticity |
|---|---|---|---|---|---|---|
| Glass powder | -14 | -21.05 | -6.67 | -20.69 | +10.54 | -6.5 |
| brick Powder | -14.44 | -34.21 | -10.94 | -25.69 | -28.73 | -22.2 |
| Porcelain powder | -15.56 | -7.89 | +13.33 | -11.8 | -7.04 | +11 |

**Table 4:** The results of laboratory tests for the adhesive material after the addition of three powders by 0.25 compared with the original bonding material without additives.

## Strengthening of concrete beams by carbon fibers :

The concrete beams were strengthened by carbon fiber and bonding material mixed with Porcelain powder by 0.25. Fig. 9 shows the test method while table 5 shows the characteristics of concrete beams before and after the strengthening . The results showed that the bearing capacity of strengthen beams by fibers CFRP and epoxy mixed with porcelain powder significantly increased by 70.97% compared with beams without any strengthening, while decreased by 2.3% compared with strengthen beams by fibers CFRP and the normal epoxy . Fig. 8 shows the relationship between load and deflection of strengthen beams by fibers CFRP and epoxy mixed with porcelain powder by 0.25 . In addition the toughness is significantly increased by 61.87% compared with the non-strengthened beams by CFRP.

| Sym. | Fy (N) | Fu (N) | Ductility | Stiffness (N/mm) | Toughness (N.mm) |
|---|---|---|---|---|---|
| A | 15100 | 36000 | 22.43 | 40810.81 | **345800** |
| E | 22200 | 63000 | 9.12 | 38947.37 | **582000** |
| P | 21500 | 61550 | 8.93 | 38392.86 | **559750** |

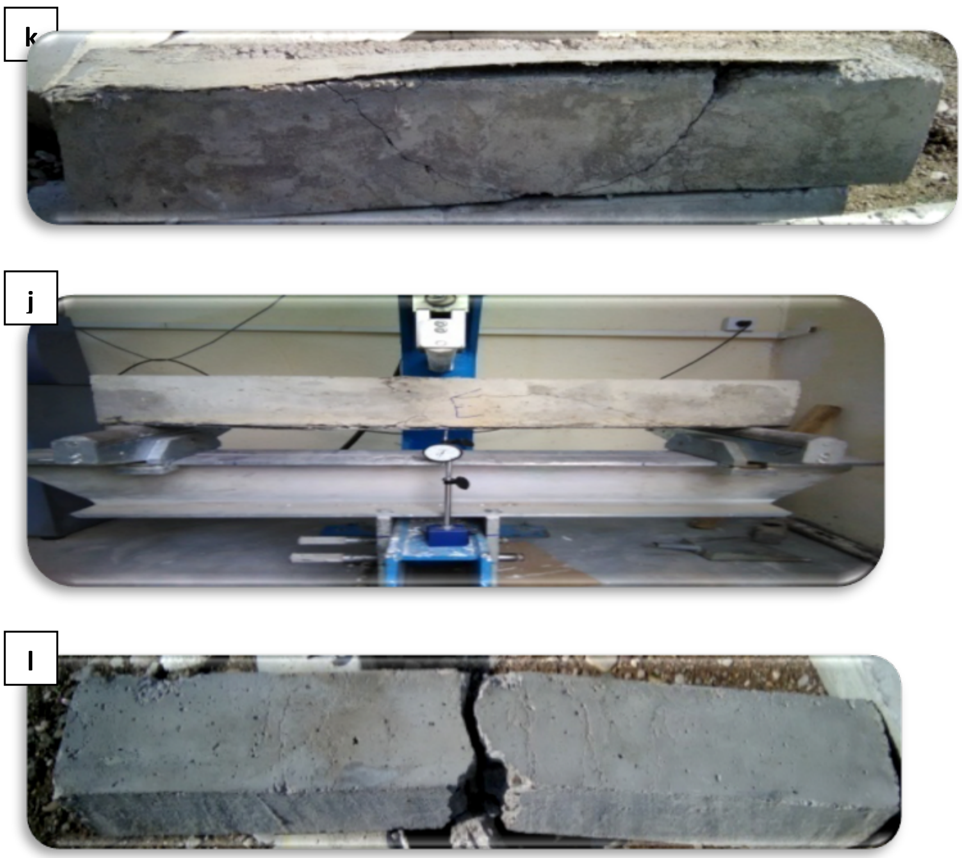



**Figure 9:** (j) Beams test. (k) Beam without strengthening by fibers CFRP after the failure. (l) Strengthened beam by fibers CFRP after the failure

**Table 5:** * Reinforced concrete properties of strengthened by fibers CFRP

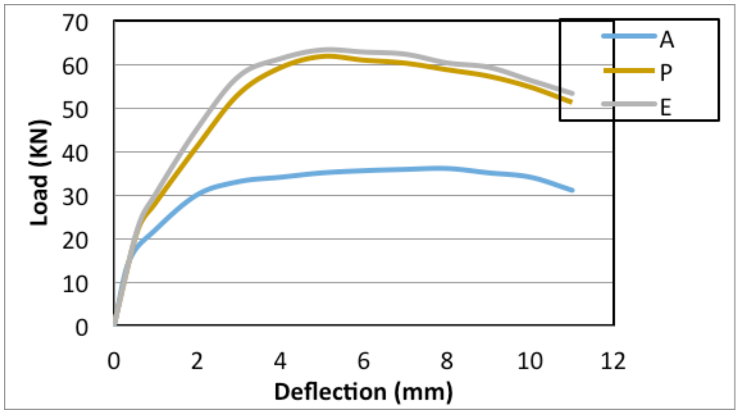



**Figure 9:** Relationship load-deflection for beams strengthened by using the bonding material improved.

## Conclusions

Through this study the following conclusions are reached :

1. The best types of powders is the porcelain powder and the best addition is 0.25 while the worst powders types is brick powder which it addition led to deterioration most of the characteristics of bonding material, while addition of glass powder led to the improvement in some properties and lower some of the other .
2. The use of the improved bonding material mixed with 0.25 of porcelain powder in strengthening the beams of concrete increased bearing capacity and toughness for beams compared with non-strengthened beams.
3. The addition of porcelain powder by 0.25 and mixing it with the adhesive material reduces the cost of this material to about quarter directly. As well as decreases the indirectly that resulted from of improved workability and the flow of the mixture and the possibility of mixing with larger amounts as a result of reduce of reaction temperature, which leads to reduce the curing time and operating hands.

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