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An experimental study on damaged cementitious mortars repaired by glass/epoxy composite materials

Chouaib Aribi[1], Aissa Bouaissi[2], Brahim Safi[1*], Mohammed Saidi[1]

[1] Research Unit; Materials Process and Environment, Faculty of Technology, M'hamed Bougara University of Boumerdes, 35000, Algeria
[2] School of Engineering, University of Plymouth, Plymouth Pl4 8AA, United Kingdom
*corresponding authors: safi_b73@univ-boumerdes.dz
mgmchouaib@gmail.com, issam3009@gmail.com , safi_b73@univ-boumerdes.dz , mo.saidi@univ-boumerdes.dz

Abstract

This paper presents an experimental investigation on the post-repair flexural response of mortars with and without damage. In order to improve the mechanical properties of the damaged mortars, which were subjected to different loads ranging between 40 % and 90 %, the mortars specimens were reinforced and repaired using two different composite materials, the first with only epoxy resin, while the second consisted of a mixture of epoxy resin and glass fiber. The results show a significant improvement in the stiffness damaged. Therefore, the reinforced specimens by a layer of resin on the lower side surface increased the bending strength by 58 %, when compared to those control samples. The reinforcement using composite resin-fiber of glass exhibited considerable increases in the safety of constructions. The SEM images of damaged samples with and without repair, revealed the impact of reinforced glass fibers-mortar on the matrix-mortar by improving theirs mechanical performances.

Key words: Cement mortar; Glass Fiber; damaged cementitious materials, Composite materials; Epoxy Resin; Mechanical Properties; SEM

1 Introduction

In civil engineering, the technique of joining is mainly used for concrete repair or reinforcement of elements in constructions, where rigid external reinforcements can be fixed on the defective structures in order to restore or increase their mechanical capacities. These reinforcements were initially introduced using steel plates in 1970, afterwards were replaced using much lighter and more sustainable composite materials [1]. Further, the process of reinforcement using fiber fabrics stuck was developed in Japan by the earlier of the 1990s, which shown a success growing in France a decade later [1,2]. These techniques showed remarkable performance by prolonging the lifespan of the defective structures with lower costs. In civil engineering, the concept of adhesive-bonded joint refers to the join applied on a cementing substrate (concrete, mortar or paste of cement) through a polymeric adhesive. This bibliographical section briefly describes the components of the assembly (adhesive and cementing substrate), and clearly provides a state of knowledge on the physicochemical interactions which could be occurred with both organic /inorganic interfaces. It is well known that many structures suffer from continuous deterioration. It has been reported that reliable systems can maintain structural integrity and extend the life of constructed facilities, which in turn lead to saving a huge amount of money from repair costs. It was stated that a high strength can be achieved on repair concrete members when external bonded fiber-reinforced plastic sheets used. Experimental studies showed an effective technique when both virgin and damaged beams were strengthened using externally bonded FRP plates [3-5]. The increase in strength exhibited by beams strengthened with FRP plates can be three times higher than their original capacity, which is believed, it depends on the steel ratio, concrete strength, FRP ratio, FRP mechanical properties and properties of the bonding agent and the level of pre-existing damage on the beams. P. A. Ritchie investigated fourteen reinforced concrete beams using steel plates, glass and carbon FRP laminates [6]. The results showed a significant increase in beam stiffnesses and the ultimate flexural capacity with approximately 116 % and 97 %, respectively, the beams made up with externally bonded plates, also exhibited other desirable features where the cracking patterns changed from several widely spaced cracks with relatively large widths to many more closely spaced cracks with much narrower widths. In 1992, Ghaleb studied the use of externally bonded fiber glass plates to increase both the flexural and shear capacity of damaged reinforced concrete beams [7-8]. The study was conducted using three repair techniques for shear damaged beams, including, FRP side plates, FRP side strips and FRP U-jackets. The results showed an observable improvement of shear capacity of those shear damaged beams repaired by FRP side strips and FRP side strips and FRP side plates by 26 and 32 %, respectively. Whereas, the beams repaired with FRP U-jackets reached the ultimate flexural capacity without experiencing a shear failure.

Much research has been done on the investigations of fiber-reinforced mortar or concrete. Numerous studies were conducted on the mechanical behavior of cement mortars reinforced with naturel fibers, steel fibers and polypropylene fibers [9-12]. Further, it was found that the ductility of fiber-reinforced composites based cementitious materials have been improved, because the fibers clogged the cracked surfaces, hence delay the onset of the extension of cracks [13]. Shah and Naaman investigated the tensile strength, the flexural strength and the compressive strength of mortar samples reinforced with steel and glass fibers [14]. The results exhibited that the tensile or flexural strengths of steel fiber-reinforced mortar were at least two to three times higher than those plain mortar samples. Nataraja, et al. observed that the variation of compressive strength of concrete reinforced with steel fibers ranges between 0 to 25 % [15]. However, the addition of steel fibers significantly increased the strain capacity and elastic deformation toughness of concrete matrix around 75 % [15].

Some authors stated that modern concretes can be designed to have a great degree of flowbility, which allows it to flow in congested reinforcement areas and fill the complicated formwork segregating [16-17]. Domone & Jin stated [18] that the evaluation of mortar flowbility is a substantial property in determining concretes' flowbility on the other hand, it is difficult to obtain well-compacted repair mortar, when applied to concrete from this side, a high fluid repair mortar may drive considerable advantages when used in narrow mould systems [19]. The main concern with high- strength mortar is increasing the brittleness when the strength increased; this becomes a serious problem in improving the ductility of High-

Strength Fluid Mortar (HSFM) (Zhou et al., 1994) [20].

Based on the literature survey described above, there is a lack of investigations on the use of resin/fibres as reinforcements and repair materials for mortar and concrete. This experimental study aims to improve the mechanical properties of the damaged mortars when subjected to different loads ranging between 40 % and 90 %., The main objective was focused to reinforce and repair the latter with composite materials using at first only epoxy resin then used a composite epoxy resin /glass fiber.

2 Materials and methodology of experiment

2.1 Materials used

Cement and mortar ordinary: In order to see the influence of epoxy resin and glass fibres on the mechanical behaviours of the damaged mortars, a total of 30 prismatic specimens with the dimensions of 40 mm x 40 mm x 160 mm were prepared and cast. The mortars specimens were prepared in accordance with the EN 196-1 standard (Table 1). The cement used during the mortar mixtures preparation was Ordinary Portland Cement (OPC) (CEM II/A 42.5).

Table 1 Composition of control mortar

Component	Cement	Sand	Water	E/C
Quantity in (g)	450	1350	225	0.5

Glass fibres: Ordinary long glass fibers of E type were used in this investigation. Their chemical composition and mechanical properties are displayed in Tables 2 and 3.

Table 2 Chemical composition of glass fibers

Elements	%
SiO_2	53
Al_2O_3	15
CaO	22
MgO	22
B_2O_3	8
F	0.7
Fe_2O_3	< 1
TiO_2	< 1
Na_2O	< 1
K_2O	< 1

Table 3 Mechanic properties of glass fibers

Tensile strength (MPa)	217.8
Elastic Modulus (GPa)	12.9
Strain at tensile fracture (%)	2.9

Resin: According to previous research, the most used adhesive resin in construction sectors is of type thermohardening epoxide systems (with 90 % of tonnage) [21]. For this reason, the conducted studies were primarily focused on the assemblies adhesives occurred through these adhesives. In civil engineering, the adhesives epoxide intended are bi--components systems, which consisted of one base epoxy (pre-polymer comprising reactive functions oxyranes) and of a hardener which is a mixture of aliphatic or cyclic amines or polyamides. Groupings functional calculate of the resin and the hardener is able to react by polycondensation at room temperature and leads to form a reticule polymeric network. A reaction enters the biphenyl diglycidylether A or DGEBA and an aliphatic diamine.

The mechanical properties of the epoxy adhesives can be rather variable according to their Formulation [22-24]. It is worth noting that that resistance in traction of the epoxy resins is definitely higher than that of cementing materials. The resin used was an epoxy resin (STR), obtained from MEDAPOXY STR EA for the resin, and EB for the hardener (Table 4).

Table 4 Characteristics of the resin

Characteristics	Résultats
Density (ISO758)	1,1 ± 0.05
Viscosity (NF T76-102) Pa.S at 25°C	0,011
Duration practices use (NFP18 810) h	1 h15mn à 20°C and 65 % Humidity
Compressive strength (NA 427) Mpa	> 70
Bending strength (NA 234) Mpa	> 25
Adherence to concrete Mpa	> 3

Characterization of the composite resin-fiber: The results of the tensile tests on the composite resin-long fibers are displayed in Table 5.

Table 5 Results of the mechanical tests on the composite resin- long fibers

Samples	Tensile strength breaking (MPa)	Elastic Modulus in traction (MPa)	Lengthening with rupture in traction (%)
average of 4 tests	133	8985	1.6

2.2 Test methods

The objective of the present work mainly focuses on the investigation of mortars damaged of the final material, which was reinforced using: s:

- Epoxy resin on a side face and the two side faces
- The composite epoxy glass/resin fiber on one face and the two side faces.

A total of 30 prismatic specimens with 40 mm x 40 mm x 160 mm were prepared then kept as control samples. Fiber-resin and glass fibers and various stackings were used as reinforcement to manufacture other 15 specimens and cured in laboratory conditions before the specimens were tested. . The samples were made in accordance to the EN standard 196-1, which explains the preparation procedures of normal mortar, also provides the measurement details of the mechanical resistance to compression and the inflection. This experimental work is divided into four stages as:

- Step 1: Studying of the mechanical behavior of three control specimens.
- Step 2: For each serial specimens, starting from the maximum values of the load to the inflection, it was applied a damage of various levels, going from 40 % of the maximum loading up to 90 %, with a step of 10 %.
- Step 3: consists of reinforcement of the damaged specimens using the following methods:
- Coating both sides faces (higher and lower) with a layer of the epoxy resin of thickness 1 to 2 mm.
- Coating the lower side face (against the third pressure point) with a layer of the resin. Applying the composites glass fiber-resin a fold on both side faces.
- Applying the composites glass fiber-resin folds on the lower side face (against the third pressure point).
- Step 4: morphological investigation using Scanning Electron Microscope analysis technique (SEM), to examine the microstructural interface zones (Interface composite-mortar).

a) Failure mode:

Typically, the rupture corresponds to the separation of two initial cracking of interdependent bodies, starts from a notch or of a preexistent defect. Its aspect and propagation speed depend on the properties of the materials used, the internal stresses to the system and other external factors (temperatures, forces applied, etc.), of the geometry of the solids.

b) Interactions cementitious materials polymers matrices

- A complex adhesion mechanism occurs, when a polymer adhesive contacts a porous cementing substrate, and resulting in Damping the surface which allows the resin to penetrate into the substrate porosities, this induce a mechanical phenomenon so-called ‘the anchoring’.
- The creation of physical and chemical cross-links to the interfaces, due to the penetration of the resin into the cementitious matrix.
- Therefore, the penetration depth depends on the properties of the porous substrate

and the resin.

- The roughness and the porosity of the cementing support contribute to increase the contact area and support the mechanical anchoring. It is believed that the treatment of the support surface make it possible to optimize the roughness of its surface [25].
- The water presents in the substrata is harmful and has a substantial influence on the penetration of the resin. This affects the drainage by capillarity, due to the saturated pores by water molecules.
- The viscosity of resin is an essential parameter in controlling the capillary flow in the porous concretes [26].

The prepared specimens were subjected to loading ranges between 40 and 90 % of the maximum loading to the inflection with a step of 10 % (Table 6). Afterwards, only those specimens were damaged under 90 % were repaired, using the epoxy resin and by a composite resin-fiber glass of type E.

3 Results and Discussions

3.1 Creating damage

To create damage, loading series ranged between 40 and 90 % were applied as shown in (Table 6).

Table 6 Various forces of damage applied to the specimen

Charge max applied (%)	90	80	70	60	50	40
Reference (N)	2653	2358	2063	1769	1474	1180

Table 7 Maximum force and lengthening of the specimen reinforced after the damage

Method of reinforcement	Max. force with the inflection (N)	Lengthening (mm)
Lay down resin on the lower side face	4660	0.62
Lay down resin on the two side faces	5250	0.71
Composite 1 pli on the lower side face	5100	1.75
Composite 1 pli on the two side faces	6400	1.85

According to the results obtained, the deterioration values after repair of the specimens damaged at 90 % ultimate force (Fig. 2) are much higher than the reference values (Fig. 1)

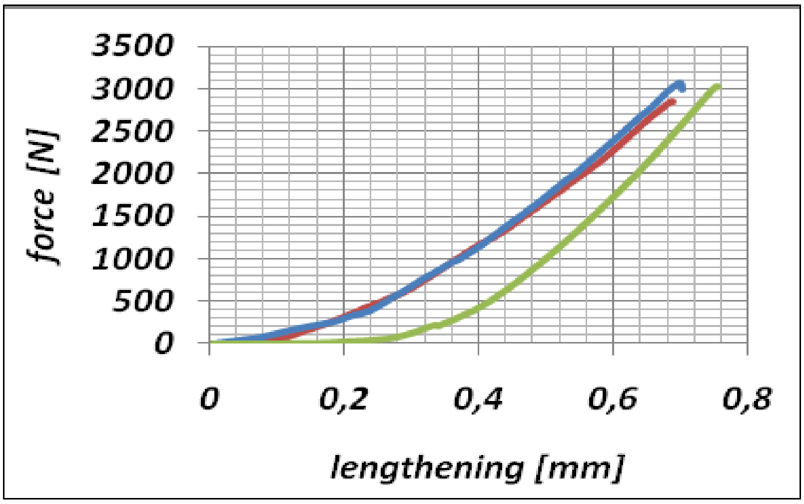

Figure 1 Curve of pilot three point bending (not damaged)

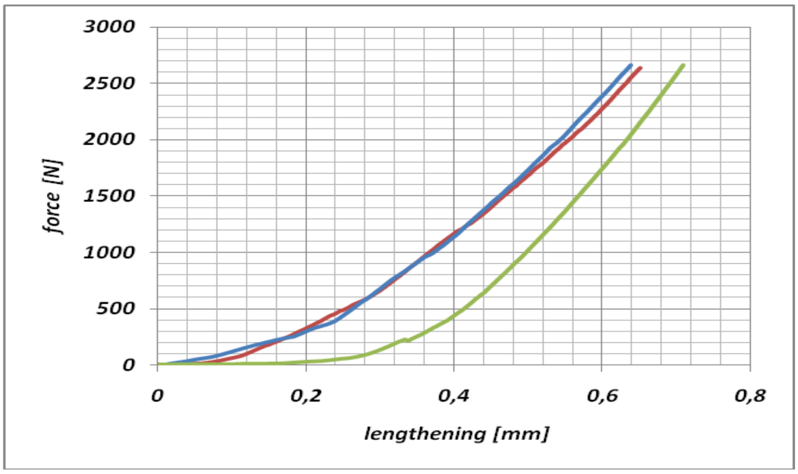

Figure 2 Curve of flexural strength third point indicating the damage of 90 % on the references

3.2 Reinforcement of the damaged specimens

To apply the reinforcement, the following steps should be followed:

Preparation of glass fiber: The glass fibers were cut carefully with dimensions of 40 x 160 mm, and then left in the flat position without folding to prevent any damages.

Preparation of the resin: Two-thirds of the resin B (2/3) and one-third of hardener A (1/3) were mixed for (3 to 5 minutes) at room temperature using an electric mixer at low mixing speed.

Application of reinforcement: to apply a layer of the resin on the surface of the specimens, a roller has been used (Fig. 3). For composite resin-glass fiber was positioned and plated manually on the support, then, one strongly pressed using the roller. Lastly, the same method was followed to apply another layer of resin with a slight of pressing to ensure that the air bubbles would not remain inside (Fig. 4). The specimens were left to cure at room temperature and relative humidity until being tested.

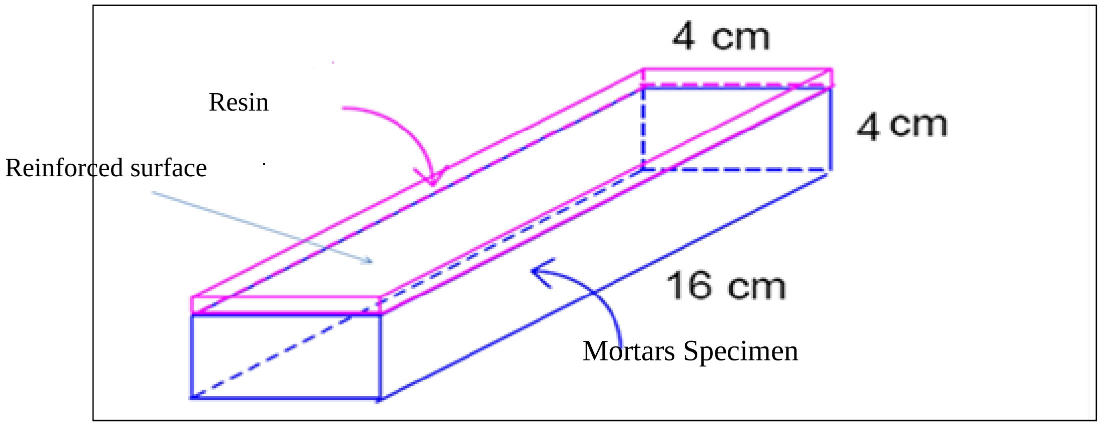

Figure 3 Reinforcement by the resin on lower surface

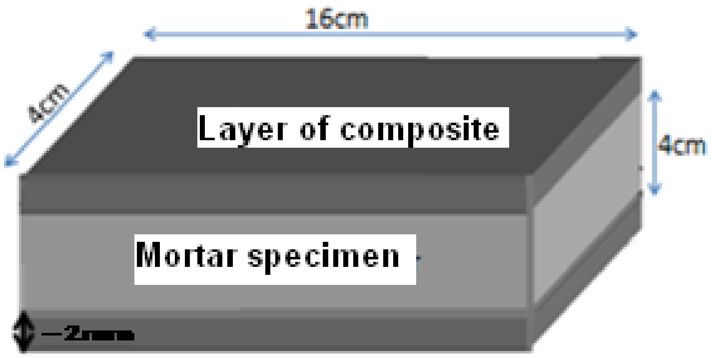

Figure 4 Reinforcement by a layer of composite on two surfaces

The results obtained do not depend on initial stacking, they are directly dependent on the method of reinforcement after the damage, with a margin of error lower than 100N (Fig. 5 to Fig. 8).

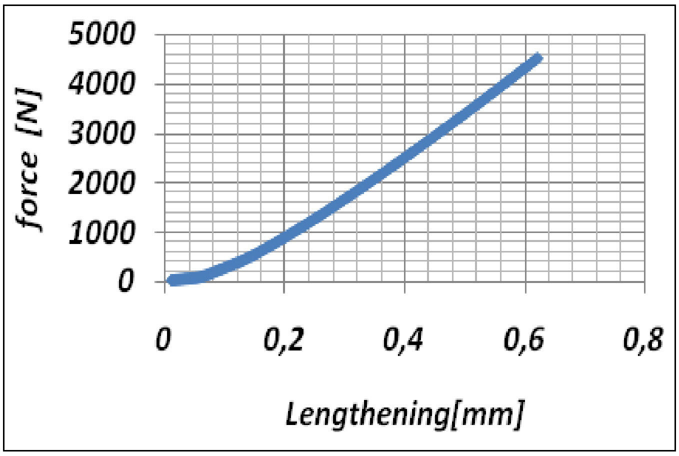

Figure 5 Curve of flexural strength third point of the specimen reinforced by the resin on lower surface

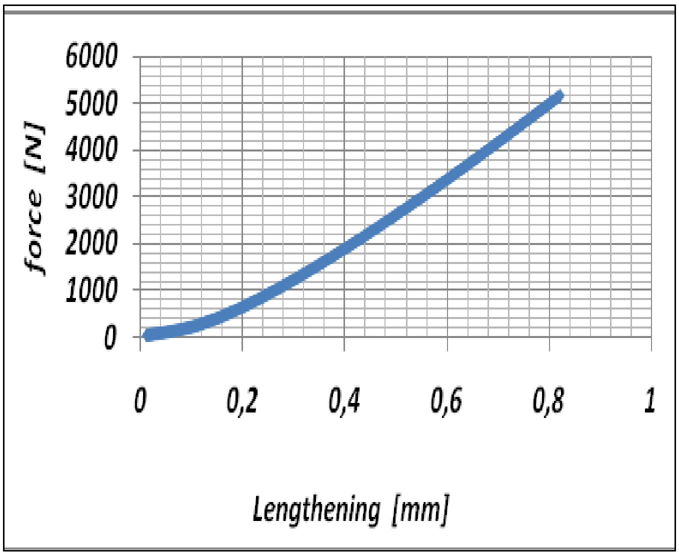

Figure 6 Curve of flexural strength third point of the specimen reinforced by the resin on two side surfaces

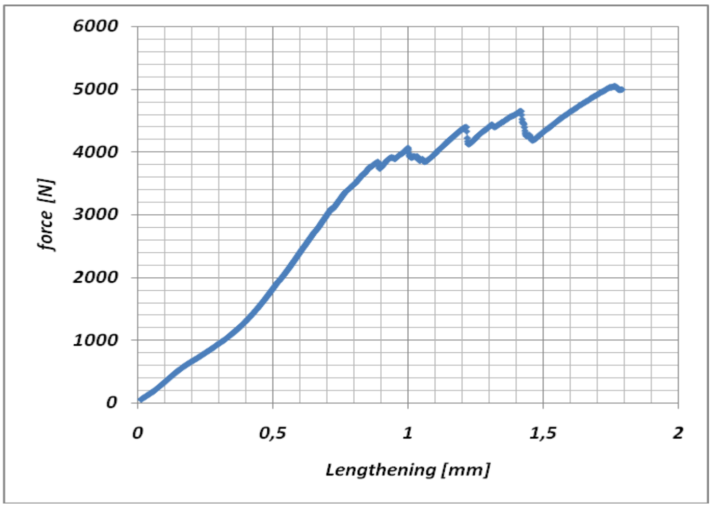

Figure 7 Curve of flexural strength third point of the specimen reinforced by the composites on side surfaces lower

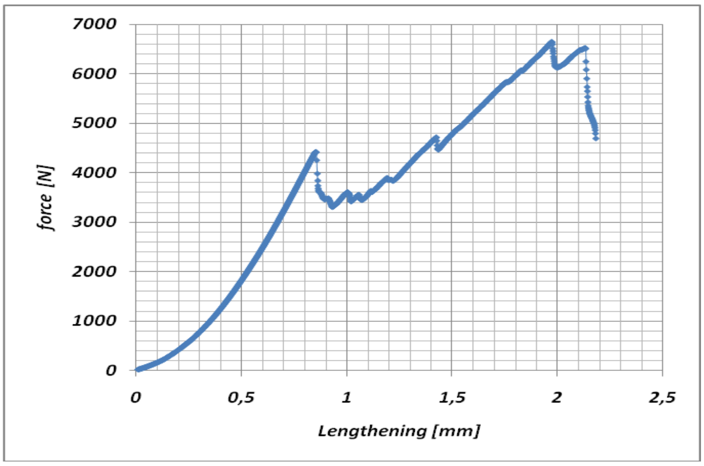

Figure 8 Curve of flexural strength third point of the specimen reinforced by the composites on two side surfaces.

The results show that the reinforced materials present more reliable mechanical properties to those of the mortar alone within the meaning of the inflection strength 3 points. However, from the mechanical behavior, each type gives a specific behavior.

For the reinforcement by a layer of the resin on a lower side surface, the force applied at the time of the inflection creates constraints which will be transmitted towards the three following zones:

- Interfacial zone resin mortar;
- The layer of the resin;
- Interior of the specimen.

The force was transferred initially towards the specimen in accordance to its length, which can also be seen by its lengthening. This last, resists thanks to the layer of resin which him confer rigidity higher than that of mortar without repair.

Continuously, this opposition will transmit the force towards the interfacial zone resin-mortar, knowing that the force of adherence of the resin is of an order of 3 MPa.

As the force applied increases, these constraints will be localized on the level of the weakest zone (the vertical plan which passes through the higher support). At the moment where the force is higher than that of cohesion of the resin on the level of the axis of intersection between the latter and the plan of the weak zone, there will be a bursting of the test-tube in two separate parts starting from the zone of plan specified already.

The addition of another layer of resin on the higher side face eliminates the effect against lengthening, due to this material, The weak increase in maximum force to the inflection (12.66 %) is a clear reason showing that the resin plays its typical role, especially, when its opposed to the bending strain [27]. (see Fig. 9 and Fig. 10)

The addition of a composite a fold on lower surface provides a maximum loading of 5100 N, which corresponds to the total wrenching of this layer starting from 4200 N with a lengthening of 10 mm. Wrenching starts without having a shearing of composite and characterized by a bending strength about the order 133,21 MPa. (Fig. 10)

The addition of another layer of composite on the upper surface eliminates these influences on lengthening and wrenching starts from 4300 N. This latter is clearly appeared on the road base and increased the total biting force up to 6400 N. (Fig. 9)

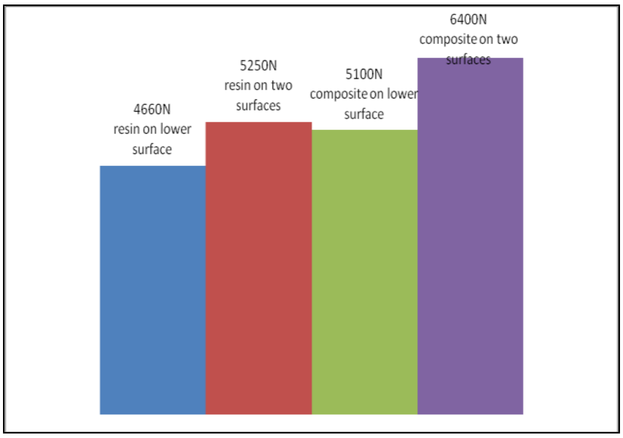

Figure 9 Histogram showing the maximum load of specimen reinforced after damage 90 %

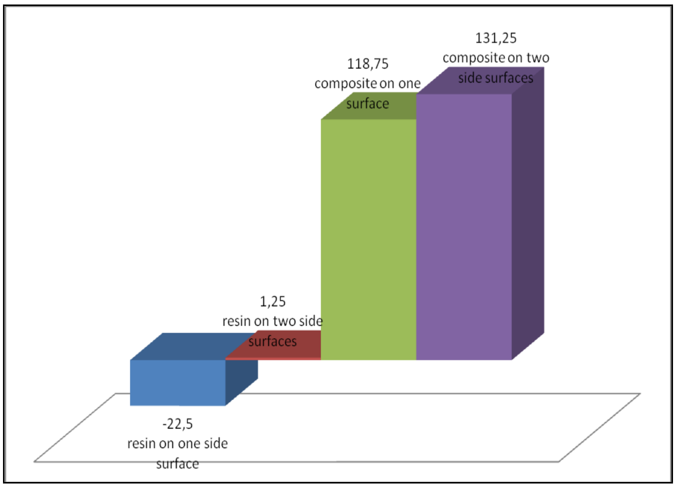

Figure 10 Histogram showing the elongation in % of the specimen reinforced after damage

3.3 Microstructural study of the interfacial zones (resin-cementitious matrix)

According to the literature, many types of interactions are likely to be established on the interface between the epoxy adhesive and the cementing substrate: specific interactions of acid-base type or hydrogen. Indeed, cementing surfaces can be considered as oxidized surfaces, due to of the presence of silicates. The oxides on the surface could then interact with polar organic compounds by an acidic or basic mechanism [28-29].

XOH+HOR→XOH….HR↔XOH2+….OR

With X = structure silicates subjacent, HOR an acid

XOH + NH2R →.XOH….NH2R ↔- XO-….NH3+R; With NH2R an unspecified amine

The most probable reaction which can occur between an epoxy adhesive and the cementing medium is the attack of the epoxy cycles by OH- ions generated from the hydration process of cement [29]. Recently, many studies have been conducted on the durability and alkali resistance of glass fibers of reinforced concrete [30, 31]. However, the long-term decline of the properties of these composites has been reported later [30]. The chemical attack on glass by the alkaline cement environment and the growth of hydration products such as calcium hydroxides, in between the filaments in the strand have been pointed out as the main reason in evaluating durability of the GFRC mechanical properties [32-36].

The following images of interface resin-mortar under the electron microscope with sweeping (SEM) are shown in (Fig.11 and Fig.12)

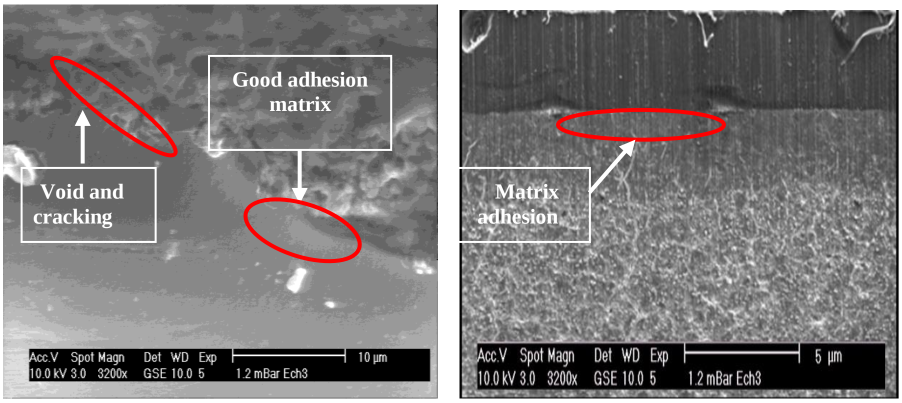

Figure 11 Te images of the resin-mortar interface by the SEM

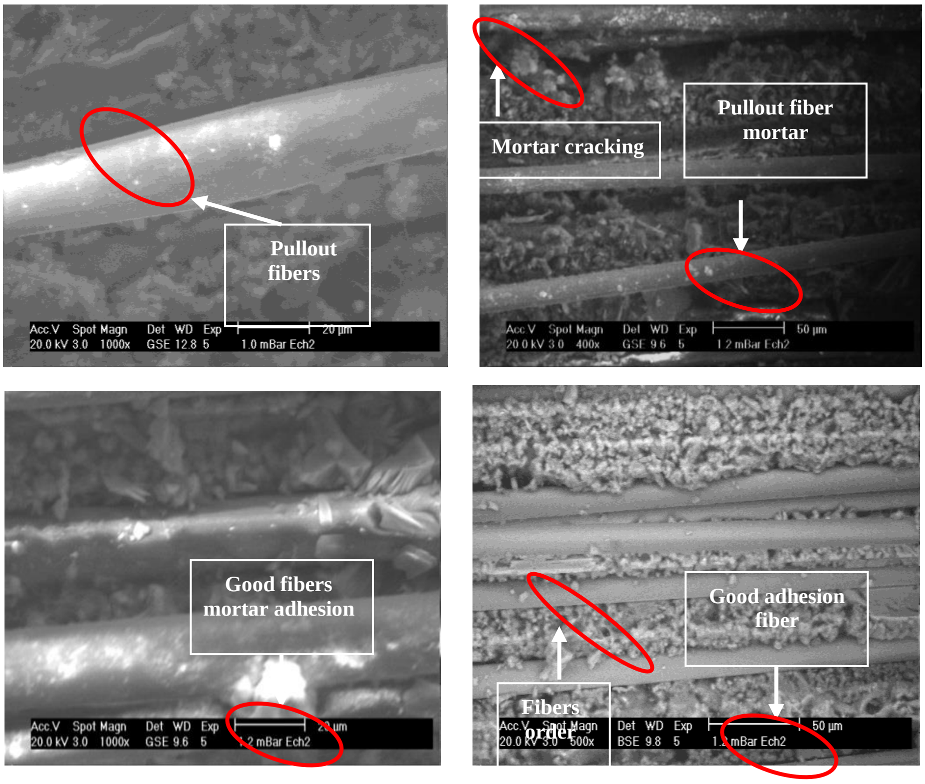

Figure 12 Series of the images of the Glass fiber-mortar by the SEM

The images present a zone of interference between the both materials resin-mortar, this accouchement can return to the one of the following causes [36-40]:

- Mechanical interaction (mechanical of materials put in contact).
- Chemical interaction by the formation of covalent or ionic chemical bonds between the resin and the cement.
- Electrostatic interaction.
- Thermodynamic interaction (the phenomenon of damping): translated by the aptitude of the adhesive to create cross-links of Vander Waals or of the type acid-bases ("hydrogen" bridges) with the mortar.

4 Conclusion

This investigative study mainly provides a clear experimental data on the influence of reinforcement cementitious material using the resin or composite resin- glass fiber, watch that, and its mechanical behaviors after subjecting to loading up to 90 %. The following conclusion can be drawn from the obtained results as follows:

1- Reinforcement by a layer of resin on lower side surface, an Increase in rigidity and the bending strength of 58 % compared to those of control specimens (not damaged), has been noted. Also, more smooth and impermeable surface has been obtained.

2- Reinforcement by a layer of resin on two side surfaces can be favourite the elimination the influence from the resin on rigidity and have improved the strength by increasing the bending strength of 73 %. Also, this method can be making two surfaces smooth impermeable thus resistant.

3- Reinforcement by composite resin-fiber, it can be reported:

a). The behavior with respect to the action of inflection translates by the wrenching of the layer of composite as the load increases until takeoff total around 5100 N for a layer and 6400 N for the two layers. That makes it possible to increase considerably the safety of our constructions, by eliminating the brutal effect at the intrinsic time of destruction (seism, explosion… etc.).

b). On the external level, these composites give an esthetic aspect par excellence, and give impermeability which is very wished for a construction of quality within the meaning of resistance to the chemical attacks.

This study makes it possible to quote qualitatively and quantitatively the influence of various stackings on the mechanical behaviors, primarily with the inflection, which will have an application on the reinforcement of the walls, and on their esthetic aspects.

In the seismic areas, it is essential to isolate the intrinsic effect of the headings from the ground on the walls in order to avoid the accidents, which can occur in a very short time, in particular, in the public buildings (schools, hospital, quote them university,… etc), the use of glass fibers and of resin is a good and recommended solution to reinforce the walls of buildings.

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