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Full Length Research Paper

Effect of size and stacking of glass fibers on the mechanical properties of the fiber-reinforced-mortars (FRMs)

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In modern day construction practice, repair and rehabilitation of structures have taken a prominent role. Indeed, the recent trend of rehabilitating and strengthening unreinforced masonry reinforced with glass fibers. In this paper, the use of fiber-reinforced-mortars (FRMs) is proposed for construction rehabilitation and reconstruction applications. A single type of fiber (glass fiber) with different length is considered; short, long and mixed. Several specimens mortars reinforced with fibers are tested in compression and flexure. Also, the stack and the microstructure of the interface glass fibers-matrix cementitious of the reinforced specimen, was examined. The results showed a remarkable increase in the mechanical resistances (50%), an important reduction of the brittleness of the reinforced mortars (lengthening higher than 40%) and a good ductility. That made it possible to increase considerably the safety of our constructions with a better esthetic aspect.

Key words: Mortar, reinforcement, glass fibers, stackings, lengthening, mechanical properties.

INTRODUCTION

Mortar is the bonding agent that integrates brick into a masonry wall. Mortar must be strong, durable, and capable of keeping the wall intact. It must help to create a water resistant barrier; and it must accommodate dimensional variations and physical proprieties of the brick when laid. The requirements are influenced by composition, proportions and properties of the mortar (Technical notes, 2008; Armwood et al., 2008).

Mortar is basically a construction material that consists of cement, sand and water. It can be added with additives to produce mortar with certain properties. Mortar is one of the materials that are frequently used in construction, and the technicality of producing good quality of mortar must be understood. If the material used is of low quality or a practice work, due to their specifications, it can cause low quality mortar. The usage of admixture such as fiber in mortar has created a revolution in producing higher strength mortar compared to normal mortar. However, there are still uncertainties on the researched quality and quality of the fibers used due to in adequate data, this explain the effect of using these fibers on the mechanical performances of mortar.

Fiber-reinforced-mortar (FRM) is a mortar made of hydraulic cements containing sand and discrete fibers it is Portland cement mortar reinforced with more or less randomly fibers in FRM, thousands of small fibers are dispersed and distributed randomly in the mortar during mixing and thus improved mortar properties in all direction fibers help to improve the post peak ductility performance, pre-crack tensile strength, fatigue strength, impact strength and eliminate shrinkage cracks (Armwood et al., 2008; Hannant, 1978). Several different types of fiber, both manmade and natural, have been introduced into preparation of mortar. However, technical aspects of fiber reinforced mortar system remained essentially undeveloped. A great deal of testing has been

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conducted on the various fibrous materials to determine the actual characteristics and advantages for each product.

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Glass fibers

Glass fibers are used in large quantities with resin matrix in the production of fiberglass composites. The common glass fibers called E glass are believed to be chemically attacked by the highly alkaline environment of cement paste, and as a result the glass-fiber- reinforced cement composites lose their strength with time. The strength reduction depends on the chemical nature of the glass and the cement paste as well as the environment. The rate of strength reduction can be reduced by using the so-called alkali-resistant glass fibers, by using an effective organic coating over the fibers or by reducing the relative humidity of the environment. Considerable research is been done to establish the long-term properties of glass-fiber- reinforced cement products (Shah, 1974).

State of practical knowledge of fiber reinforced mortars (FRM)

Fiber reinforced mortars (FRM) (Arya et al., 2002), have been part of the construction industry for a long period of time. Though the mechanics of cementitious based matrices for fiber reinforced composites was explored during the 1970s, with intrinsic models developed (Taylor et al., 1975), no direct confinement applications were devised. Though slow progress was made, it was not until the 1990s– developments for permanent forms for new construction (Aveston et al., 1971) and rehabilitation (Sato et al., 1999; Dolan et al., 1999) were made, with an emphasis on applications for shear and/or flexural strengthening (Balaguru et al., 1997; Daniel et al., 1990). Recent studies (Foden et al., 1996; Garon et al., 2001) have concluded in their findings that organic matrices can be as effective as inorganic ones for composite strengthening in flexural, shear and confinement applications, thus showing the capability of inorganic matrices versus organic ones. Further research is being undertaken to study the use of textile/mesh type reinforcement instead of fiber sheets for concrete confinement, showing that significant increases in compressive strength and deformation capacity can be attained (Kurtz et al., 2000; Wu et al., 2006; Toutanji et al., 2007). A field application using a fiber glass mesh embedded in a cement-based matrix for the seismic strengthening of all dome roofs of the Basilica of Santissima Annunziata in Sicily (Triantafillou et al., 2006) shows the versatility of inorganic matrices and their potential for implementation.

Thanks to their properties, the composite materials make it possible to better mobilize the intrinsic resistance of the concrete or the mortar with like consequence a reduction of the sections, to carry out large-sized thin parts and to give a greater architectural freedom (Triantafillou et al., 2005; Bournas et al., 2007; Morandini et al., 2007).

The objective of this study is to evaluate the effect of the reinforcements by materials (glass fibers) of Type E (short, long and mixed) with different stacking on the behavior and the mechanical resistances from the mortars, the second part is devoted under investigation microstructure of the interface glass fibers-matrix cementitious of the reinforced specimen by SEM.

Table 1. Mixture of the reference mortars.

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

Experimental program

The experimental program was developed with three main purposes:

(1) To explore different types of technical empilement of glass fiber into mortar.
(2) To explore the effect of different size of glass fibers on the mechanical properteis
(3) To evaluate system compatibility and interface fibers-matrix by testing confined mortar specimens in flexural and compressif test.

MATERIALS AND METHODS

In order to see the influence of these materials (glass fibers) on the mechanical behavior of the mortars, we made 6 prismatic specimen 4×4×16 cm of references, and 54 specimen with reinforcements by long glass fibers, short and mixed, and with various stackings (Table 1) (Toutanji et al., 2000; Carlac'h et al., 2002). Cement used is a Portland cement made up of Type CPJ CEM II/A 42.5 according to the standard norm (ENV).

Mixture and technical reinforced of mortar

The mortars are prepared according to the European standard EN196-1 (Table 1).

Table 2. Various stacking of the specimen mortar.

Category (notation)	Stacking
0-0-0	No stacking.
0-S-0	SF in the medium.
0-L-0	LF in the medium.
S-0-S	SF on the faces Higher and lower
L-0-L	LF on the faces Higher and lower.
L-0-S	LF on the higher face. SF on the lower face.
L-S-L	LF on the two faces. SF in the medium.
S-L-S	SF on the two faces. LF in the medium.
S-S-S	SF on the two faces and in the medium.
L-L-L	LF on the two faces and in the medium

(* Notes: LF: Long fibers; SF: Short fibers).

Table 3. Chemical composition of glass fibers used.

Element	SiO_2	Al_2O_3	CaO	B_2O_3	F	Fe_2O_3	K_2O and Na_2O
(%)	53-54	14-15.5	20-24	6.5-9	0-0.7	< 1	< 1

Table 4. Mechanical properties of glass fibers used.

Samples	Tensile strength (MPa)	Elastic modulus (GPa)	Lengthening in traction (%)
Fiber glass	217.76	12.87	2.91

The methods of reinforcement are as follows:

1. The long fibers are piled up on the side surface in an equidistant way. In order to protect fibers, an impregnation coat of mortar is applied to the moulds to a depth of 5 mm.
2. Then short fibers are piled up on all surface (4×16) in the form of a sheet of a fold to a 5 mm depth with an impregnation coat like the preceeding case.
3. For stackings in the medium, the fibers are laid out in the middle of the specimen. Table 2 summarizes all the reinforcements used with various stackings of the specimen.

The fibers are piled up in the mortar in a fresh state before are hardening.

Chemical composition and mechanical properties of glass fibers

The glass fibers used are of ordinary fibers of Type E of chemical composition and mechanical properties given respectively by Tables 3 and 4.

Mode of rupture

In a general way, the rupture corresponds to the separation of two initially interdependent bodies. Cracking is generally starting from a notch or of a preexistent defect. Its speed on propagation and its aspect depend on the properties of materials, the internal stresses to the system and those exerted on this one by the external medium (temperatures, forces applied, etc), of the geometry of the solids (Maugis et al., 1986). All mechanical tests were measured using the universal testing machine 250 kN (made by ZWIKH). The flexural test was carried in Three-point bending test (ASTM, 2003-C947).

RESULTS AND DISCUSSION

Flexural strength

In order to have a good representation of the results, we calculated the average resistance of 3 specimen for each reinforcement and the specimen of reference. The results are represented in Figures 1 to 10.

The curve characterizing the references mortar shows a linear brittle behaviour. A positive effect of the fibers was observed visually; the samples with fibers disintegrate and stayed relatively compact until high displacement (up to strain of about 0.8 mm), only containing number of smaller cracks.

The results obtained in Table 5 and Figures 1 to 10 present an increase in the value of the maximum loading

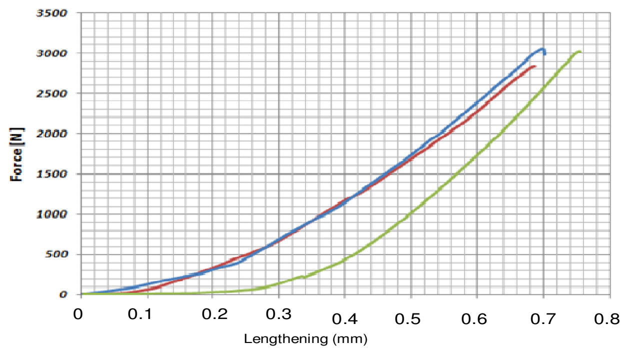

Figure 1. Flexural load-deflection curves for mortar reference 0-0-0,R_f = 2948 N.

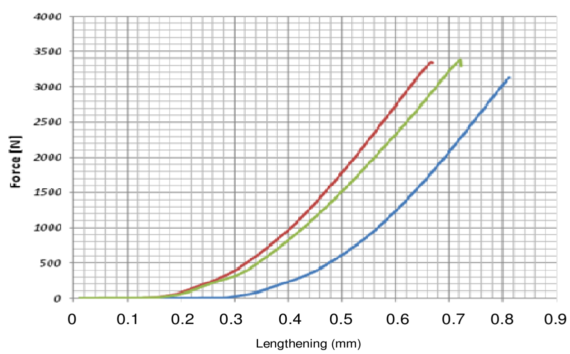

Figure 2. Flexural load-deflection curves for 0-S-0, R_f =3390 N.

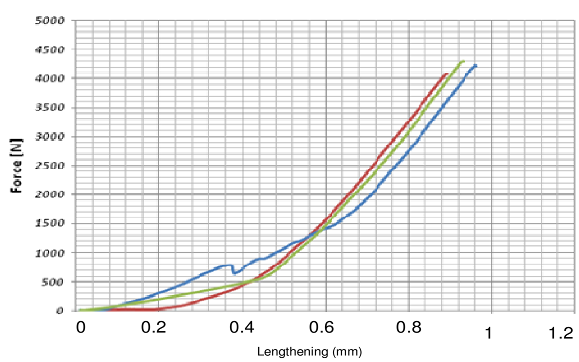

Figure 3. Flexural load-deflection curves for point 0-L-0, R_f =4080 N.

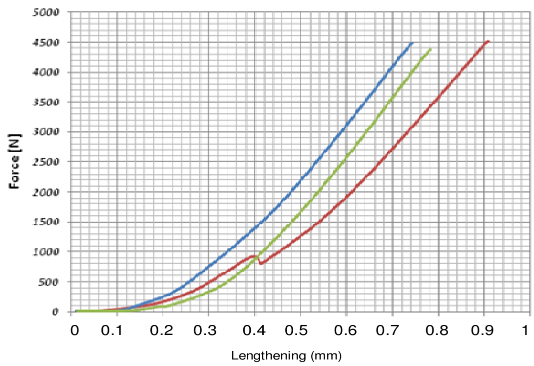

Figure 4. Flexural load-deflection curves for S-O-S, R_f =4460 N.

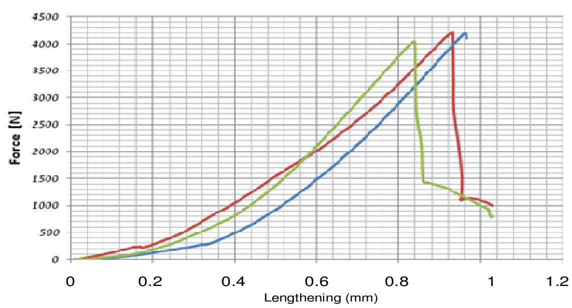

Figure 5. Flexural load-deflection curves for L-0-L, R_f =4190 N.

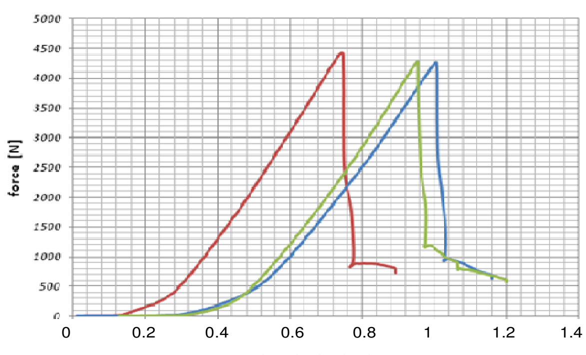

Figure 6. Flexural load-deflection curves for S-0-L, R_f =4320 N.

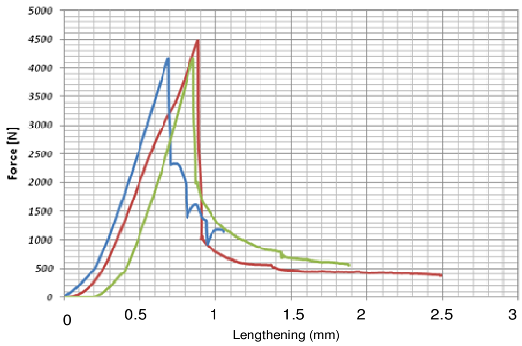

Figure 7. Flexural load-deflection curves for L-S-L, R_f =4260 N.

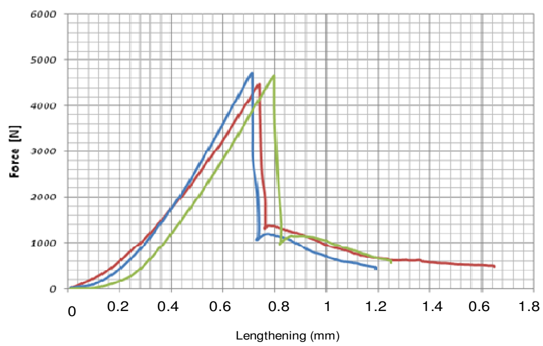

Figure 8. Flexural load-deflection curves for S-L-S, R_f =4630 N.

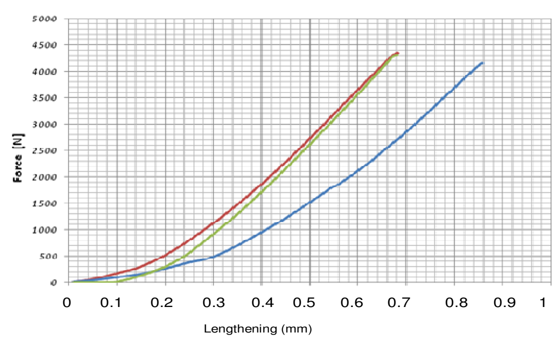

Figure 9. Flexural load-deflection curves for S-S-S, R_f =4370 N.

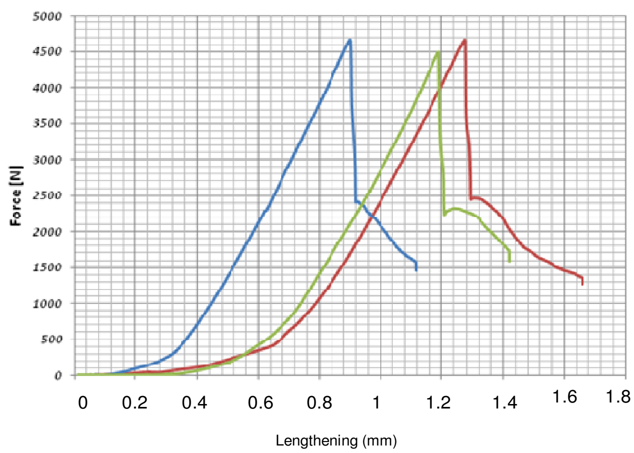

Figure 10. Flexural load-deflection curves for L-L-L, R_f =4620 N.

Table 5. Profit of load, lengthening and strength of release of phase 2 according to stacking.

Category	Max.average charge with the inflection (N)	Profit of load (%)	Average lengthening of 1st phase (mm)	Force release of 2nd phase (N)
Reference				
0-0-0	2948	‘’	0.7	‘’
0-S-0	3390	15	0.5	‘’
0-L-0	4080	38 .4	0.9	1500
S-0-S	4460	51.3	0.6	‘’
L-0-L	4190	42.1	0.9	1200
S-0-L	4320	46.5	0.7	1000
L-S-L	4260	44.5	0.7	1000
S-L-S	4630	57.0	0.7	1500
S-S-S	4370	48.2	0.6	‘’
L-L-L	4620	56.7	0.8	2500

to the inflection and a behavioral change with respect to this action (Figure 11). With regard to the behavior, two changes are observed:

1. Lengthening of the specimen reinforced compared to the reference (Figure 12).
2. Appearance of a phase of behavior for stackings with long fibers (Figure 13).

This lengthening (displacement) indicates the fragile behavior for the mortar, it is weak in the case of the short fibers compared to long fibers. For the mixed specimen (short fibers and long fibers), lengthening is identical to that of the specimen of references. All stackings which contain long fibers present a second phase of behavior.

The behavior of these specimen is intrinsically related to the interface cementitious matrix fibers. When the cracking of the specimen is initiated, the transfer of the efforts takes place towards fibers via the interface. First of all, at the time of the application of the maximum loading, there is a shearing of fibers on the level of the interfacial zones, the subjacent fibers start to apply an intrinsic contraction against the support of application of the force (high speed with 10 N/s). What encourages the machine to continue its operation until the shearing of

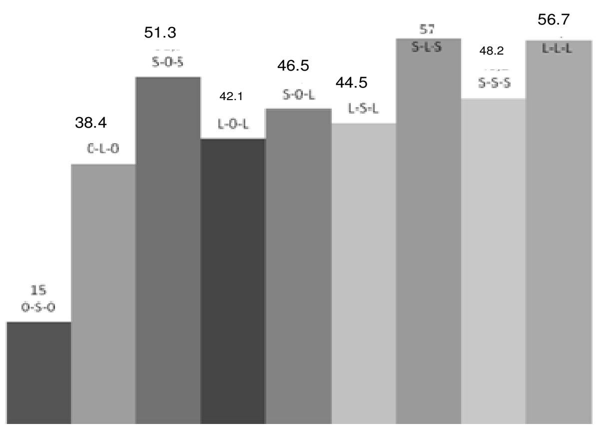

Figure 11. Maximum loading in %.

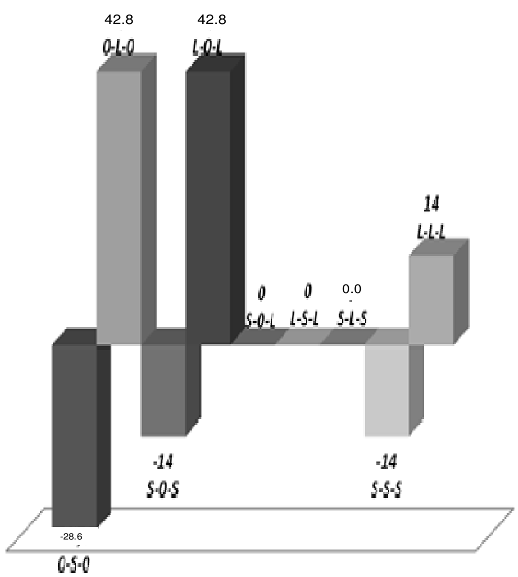

Figure 12. Lengthening in % according to stacking.

these fibers, then, this mechanism is repeated in a frictional way until the moment when the force of slip of fibers becomes lower than its breaking stress, in this case, there is a wrenching of fibers towards outside (Figure 13). The force of release of the second phase is high compared to the maximum force in the case of the

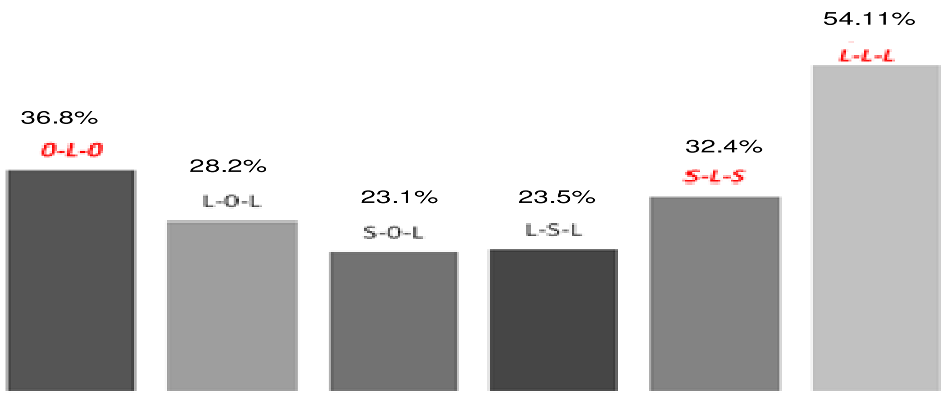

Figure 13. Force starting of the second phase compared to the maximum loading of inflection in %.

Table 6. Compressive strength and displacement.

Sample	Max. average compressive load (MPa)	Displacement (mm)
Ref. Mortar 0-0-0	35	0.8
0-S-0	37	1.0
0-L-0	33	1.0
S-0-S	45	1.2
L-0-L	38	1.8
S-0-L	40	1.8
L-S-L	42	2.2
S-L-S	43	1.4
S-S-S	50	1.2
L-L-L	32	2. 4

stacking of the type L-L-L (Figure 10), S-L-S (Figure 8) and 0-L-0 (Figure 3). This results in the positioning of long fibers in the middle of the specimen which gives better results within the meaning of the intrinsic behavior with respect to the actions of inflection.

Compressive strength

The results of the mechanical resistance to compression are summarized in Table 6.

The maximum value with compression decreases when the stacking of reinforcement contains only long fibers. In the case of stackings with short or mixed fibers, one notices an increase in the compressive strength, which is due to the distribution of short fibers on all surface (Figures 14 and 15).

These results show that the introduction of long fibers generates an additive vacuum with the original vacuum of cementing materials, and takes considerable values as shown in Figures 17 and 18 by SEM.

These images (Figure 16) show that, the long fibers create weak zones during compression the cracks appear in these zones. Contrary to short fibers or the remains remain attached to fiber.

Micro-structural analysis of the interface fiber-mortar

The analysis of the microstructure of the interface fiber-mortar is carried out by electron microscope with sweeping (SEM) and it gave the images shown in Figures 17 and 18.

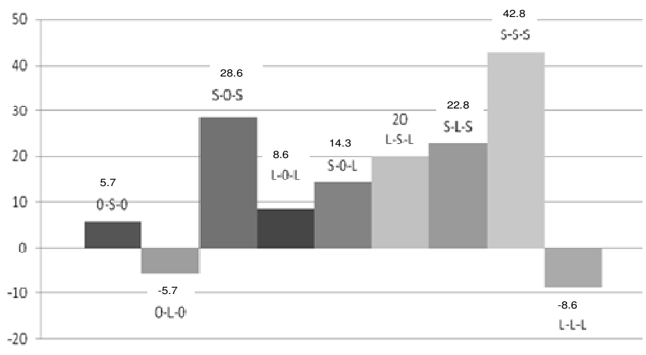

Figure 14. Compressive strength in % of the specimens reinforced compared to the reference.

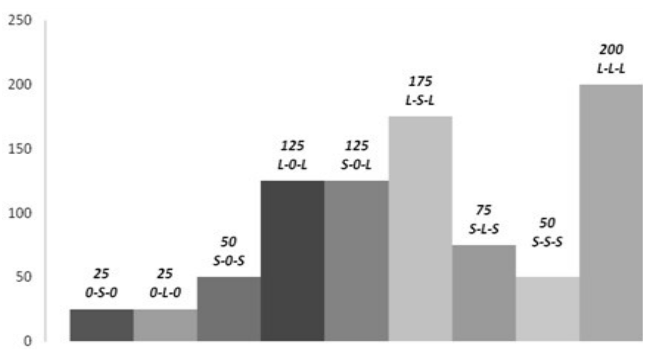

Figure 15. Displacement in % compared to the reference specimen.

Figure 16. Specimen 0-L-0 and C-0-L having undergone a compression.

The results obtained by electron microscope with sweeping (SEM) show that on the level of the interface, it does not have an adherence between fibers and cement (there is a vacuum), with the result that the impedance of the second phase of behavior is due to friction between fibers and the mortar on one hand and between the long

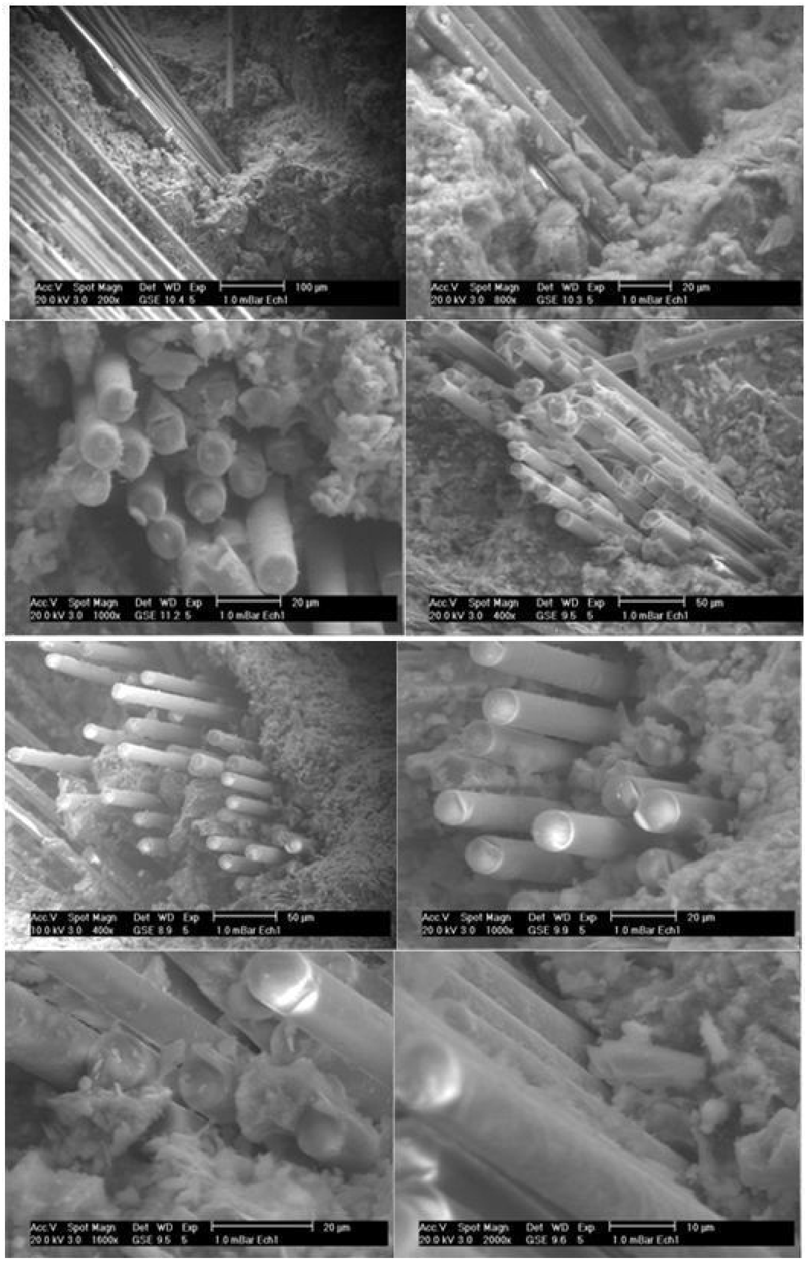

Figure 17. Microscopic aspect of the interior matrix of mortar by the SEM.

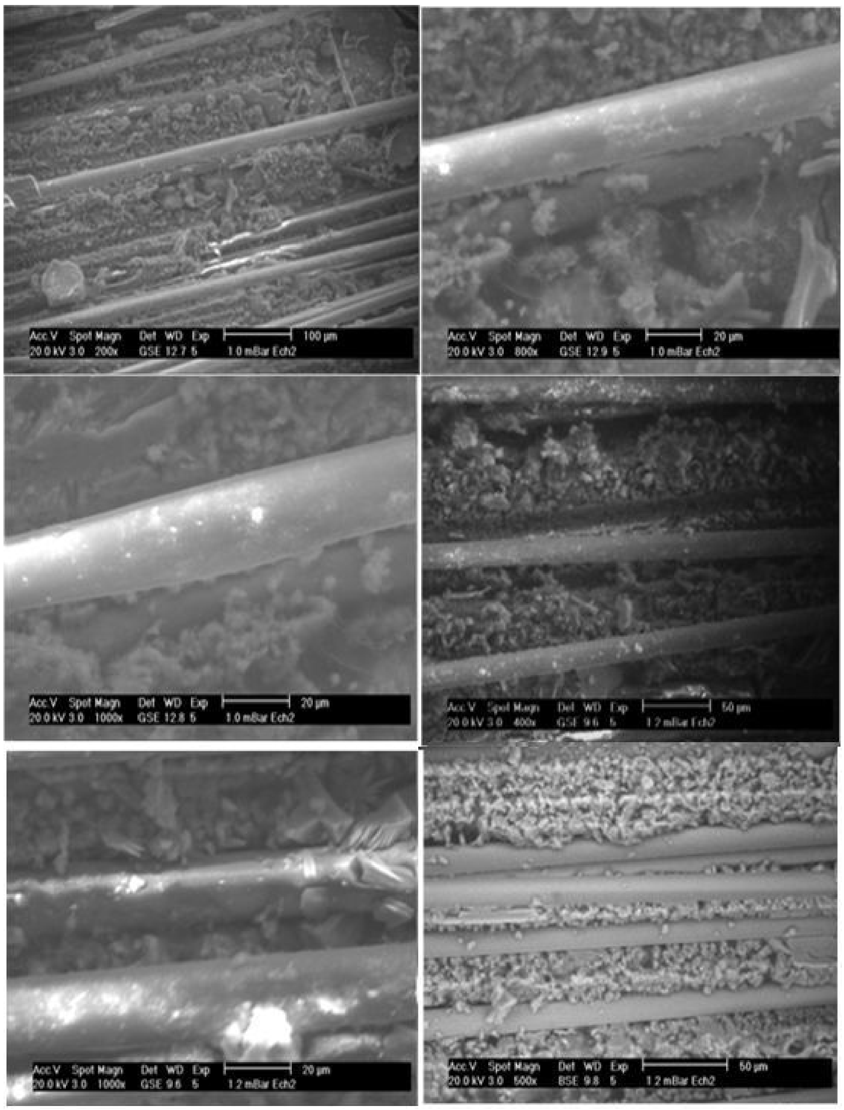

Figure 18. Microscopic aspect of the interface fibers long-mortar by the SEM.

fibers on the other hand (which present a vacuum between them). These accumulations of vacuums create the weak compressive center against the vacuums.

These images also show that the long fibers create weak zones during compression and the cracks appear in these zones. Contrary to short fibers or the remains attached to the fiber, these images present also the beginning of the attack of fibers since the fibers of the Type E do not resist in the basic medium like the mortar of P_H=13.

Conclusion

This study enabled us to see the influence of glass fibers short, long or mixed on the resistance and the mechanical behavior of the specimen of mortar, including the sequence of various stacking. According to the results obtained, one can draw the following conclusions:

Influence long fibers

(a) Increase in the compressive strength (more than 50%).
(b) Improvement of the intrinsic behavior with respect to this action, by appearance of a second phase of behavior due to friction fiber-fiber and fiber-mortar. This behavior makes increase the resistance of constructions.
(c) Reduction in the brittleness of the specimen, which become ductile (increase in lengthening more than 40%).

However, these fibers slightly decrease the compressive strength from 5 to 9%, this reduction is due to the increase in the pores create by fibers and results in displacement downwards during compression. The localization of the vacuum around and between fibers creates weak zones. This develops the cracks at the time of compression.

Influence of short fibers

(a) Increase in the rigidity which results in the reduction in lengthening compared to the reference.
(b) Increase in the flexural strength without appearance of the second phase.
(c) Increase in the compressive strength and improvement of the behavior with respect to this action translated by the attachment of the remains of mortar, this is done to increase the state of safety of constructions.

Influence short fibers and fiber long (mixed)

(a) Increase in the flexural strength (more than 40%) without influence on the rigidity is stacking.
(b) Appearance of the second phase of behavior due to long fibers.
(c) Increase in the compressive strength (more than 14%) and to carry out the attachment of the pieces of the

mortar after this action.
(d) Creation of the vacuum which results in displacement during compression.

This study makes it possible to quote qualitatively and quantitatively the influence of various stacking on the mechanical behavior, 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 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, halls of residence,… etc), the use of glass fibers is a good solution to reinforce the walls, the study also shows that:

(a) The use of long fibers within the mortar improves the behavior with the inflection, increasing the ductility.
(b) The use of short and long the fibers mixtures (mixed) makes it possible to avoid the reduction in the maximum value of load to compression due to long fibers, and lowers the adverse effect of these fibers on behavior during compression.

This study can be supplemented by the evaluation of the durability of the mortars and the concretes with these reinforcements in various corrosive conditions which will be the subject of our next work.

Comment [h1]: me be flexural strength

Comment [h2]: why(relation with increase more than 50%)

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