EXPERIMENTAL STUDY OF FIBER REINFORCED MORTARS THAT ARE USED IN THE RESTORATION OF TRADITIONAL BUILDINGS

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Abstract

In the Testing & Strength of Materials Laboratory of ASPETE, a research is carried out aiming in investigating materials and ways of improving them, so as to deal with real problems that arise during their applications, in construction and industrial fields.

This presentation is referring to a part of the research that is realized in the Testing & Strength of Materials Laboratory of ASPETE, by the members of the above presented team, together with undergraduate and post graduate students of the School.

The subject of this specific research is mortars which are used in reinforcements and repairing of structural elements of existing buildings, that can also be applied in renovation and reinforcement of traditional buildings. In order to investigate the various applications of the above described mortars, specimens of different composition, reinforced either with glass or polypropylene fibres and un-reinforced. Furthermore, all the above specimens have been manufactured also with the technique of spraying, since it is considered to be the main application method of repairing mortars.

The influence of mortars' exposure to high temperatures (fire conditions) has been especially investigated and the way the exposure time and the amplitude of temperature affect the values of mechanical properties of the specimens. The specimens were manufactured, cured and then subjected to the tests of compression, splitting tensile and bending, before and after their exposure to high temperature. The results of the tests are presented and compared in the corresponding diagrams.

Key words: *Restoration of Traditional Buildings, glass fibers, polypropylene fibres, reinforced mortars, sprayed mortars, marble aggregates*

Introduction

A comprehensive presentation of experimental studies on building materials that was carried out in Laboratory of Testing and Strength of Materials of The Department of Civil and Structural Engineering Educators of Pedagogical and Technological Education School of Athens is given in this work. The basic research team is consisted of the above mentioned writers with the collaboration of undergraduate and post graduate students of the School. The main research interest of this laboratory during the last decade has focused on the study of repairing mortars and already a great number of critical factors and conditions that affect their behavior, has been investigated. The main outcomes that have emerged, are presented with basic suggestions for the completion of the project.

The certified by ISO9001: 2008, Testing and Strength of Materials Laboratory provides a variety of services to the Institution, such as:

- education of the undergraduate students by performing Educational Tests
- testing materials for companies and individuals
- applied research

The Laboratory having adequate equipment, suitably trained staff and seeking cooperation with dynamic researchers and leading companies in the area of production and application of mortars, has obtained the ability to perform essential and fundamental studies in the following research fields:

- testing of materials in order to obtain their mechanical properties in various types of unidirectional and multi axial loadings by tensile, compressive, bending, shear and torsion forces and from buckling states, both for plain and reinforced mortars and other building materials
- the determination of crucial physical, physico-chemical and mechanical properties of building materials such as drying shrinkage, thermal expansion and contraction, water permeability and water absorption, hardness, durability, flowability, workability, porosity and more
- the facility of exposure to extreme frozen conditions, to very high temperatures and hydration and the description of their behavior changes by these exposures
- non-destructive testing of materials and structures, such as ultrasonic steel reinforcement detection, indirect determination of strength of materials and other mechanical and physical properties of mortar by ultrasonic inspection, schmidt hammer testing and pull out tests

The prime aim and principal direction of the Laboratory research orientation is that the whole research effort conducted over the investigated materials and their improvement, is done in such a way as to overwhelm problems arising from their application in place, such as those appear in construction industry.

So, mortars which are used to reinforce and repair elements of existing modern buildings that are also applied to traditional ones, have been studied in the laboratory. In addition, these mortars have been studied also as sprayed ones, since this is considered to be the main method for the application of repairing mortars.

The mortars that have been investigated in the laboratory during the most research cycles typically contain marble classified between 0-4mm in diameter as aggregate, high strength cement grade in a ratio of 1:3 and water in a ratio of about 0.55.

Marble aggregates are selected in order to investigate the potential utilization of marble by-products from the quarry industry and processing of marble. The results that these marble-concrete mortars have given were compared with mortars of the same composition but with limestone aggregates. The outcome of this comparison was not only encouraging but also really promising very good perspectives.

Proceeding even further, these mortars were studied adding in their bulk mass glass and polypropylene sort distributed fibers with different volume percentages.

The experimental study of the above reinforced and not mortars that was held by testing suitable manufactured specimens under compressive and bending – tensile stresses and also their inspection by the ultrasonic device in normal conditions and under the influence of ultra high temperatures (~1000^{o}C) for extended time periods in advanced high temperature laboratory furnaces, gave significant results for determining their remaining strength and the abilities that appear for an effective action and their restoration.

Preparing the Speciments

For the manufacture of test specimens, adequate mixing of cement and aggregates grains in dry conditions is demanded and then polypropylene and glass fibers are added. Polypropylene and glass fibers are separated fully. After the addition of a strictly specified water amount and adequate mixing the mixture casts in steel moulds with dimensions 160mm x 40mm x 40mm. The casting of mixture in moulds is followed by adequate compensation with the help of a vibration table. The moulds remain at their place to cure for 24 hours and then the specimens are placed in a water tank (with temperature 20^{o}C) in order to complete their curing for a total standard period of 28 days.

After the lapse of this standard time they are placed in room conditions, with relative humidity of 50% and temperature of 22°C for another 28 days, so as they equilibrate and the additional moisture is removed.

Experimental Results

A. Study of cast specimens unreinforced and fiber-reinforced with various percentage of glass and polypropylene fibers in bending and compression.

At compression test, specimens were loading both parallel and perpendicular to mortar's specimens layering as shown in the following figure.

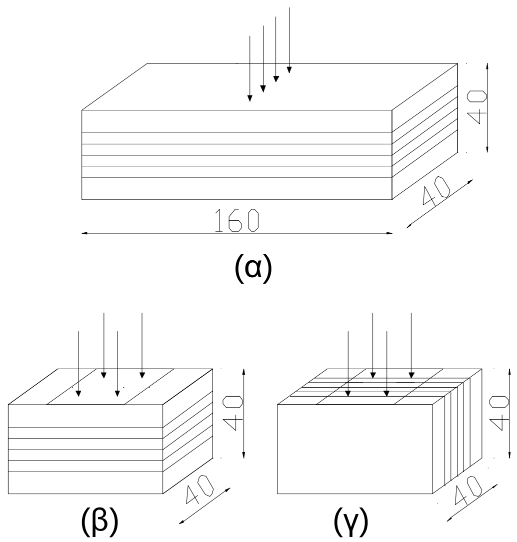


Figure 1: Bending loading perpendicular (a) and compressive loading perpendicular (b) and parallel (c) to specimen layering. (dimensions in mm).

Figure 2: compressive loading

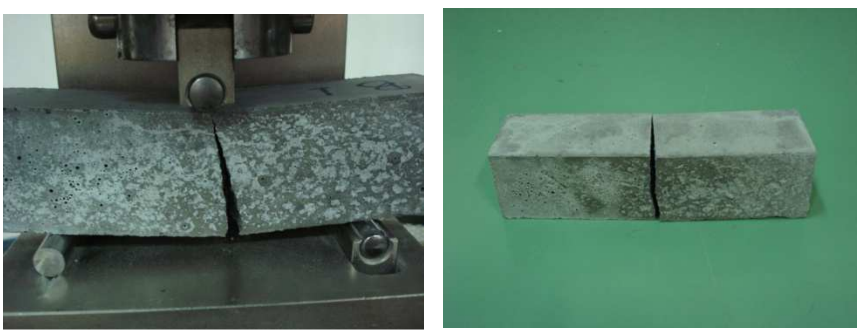


Figure 3: bending loading

Results

Glass fiber-reinforced mortars

The figure below, shows the variation of the compressive strength, in perpendicular and in parallel to specimens layering direction for fiberglass mortar. It is obvious that an increased strength appears (of about 30 to 35%) for all glass percentage specimens' compression loading parallel to mortars' layering in contrast to perpendicular to this layering loading. Obviously, the appearing specimen inner mortar microstructure from the production stage, leads to anisotropy with weaken axis transverse to specimen layering and strong one on the plane of layers. From the figure the pure conclusion that the adding of even a small amount of fiber as in our case, causes a satisfactory increase of compressive loading that starts from 10% of the un-reinforced mortars for 0.07% fiber percentage and reaches up to 20% for adding 0.26% fiber volume percentage, can be extracted. Also, it can be noticed that the rate of increase of strength is constantly decreasing with greater percentage, and thus the higher efficiency of the used fibers, being displayed in the lower level of 0.07% volume percentage.

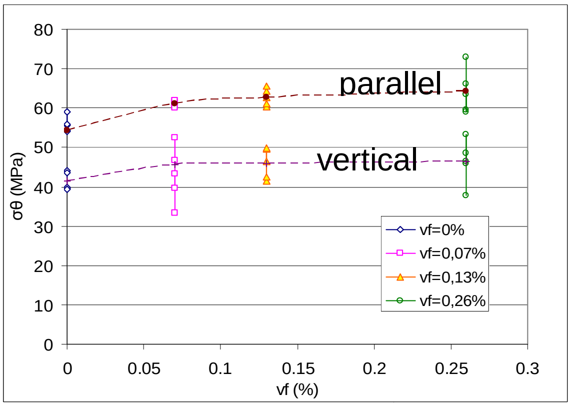


Figure 4: Compressive strength variation of glass mortars parallel and vertical to fibres reinforced mortar specimens

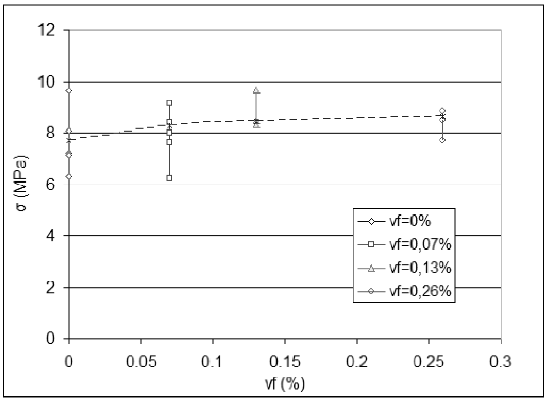


Figure 5: Bending strength variation of glass fibres reinforced to specimen 's layers.

A similar behavior is observed for the bending strength of mortar reinforced with glass fibers. The addition of fibers leads to an increase of their tensile strength of about 10 to 15% percent compared to un-reinforced ones.

Polypropylene fiber reinforced mortars

Then, the variations of compressive strength parallel and perpendicular to mortars layering is given according to fiber volume percentage. As in the case of mortar with glass fibers, an intensive anisotropy appears in the various directions. The strength parallel to layering gives higher values of about 25 to 55% compared to strengths transverse to layering. Also, it can be concluded that the addition of polypropylene fibers causes little changes in mortar's strength of about 5 to 10% for the range of polypropylene volume percentage that inspected.

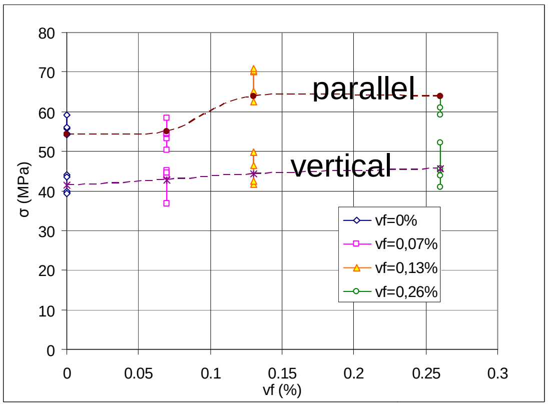


Figure 6: The variation of the compressive strength polypropylene fiber reinforced mortars parallel and perpendicular to their layering

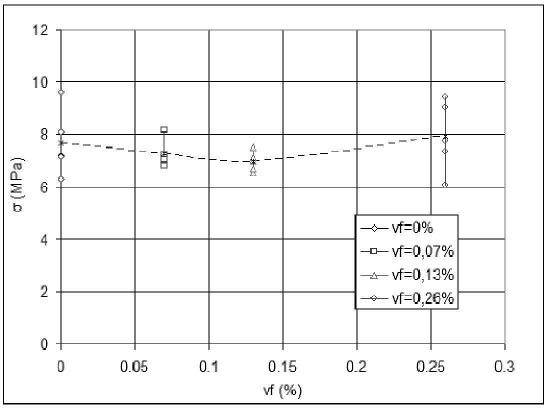


Figure 7: The variation of the of bending strength of polypropylene fiber reinforced mortars

In the above figures it is observed that the flexural strength at low fiber percentages does not indicate noticeable changes, apart from 0.26% percentage with an increase of about 10%.

Comparison of compressive and tensile strength of fiber reinforced mortars for both polypropylene and glass fibers shows a proportion of about 1/6 tensile to compressive strengths, which is within the expected range according to the existing references.

In the following figure (bending test), fiber-reinforced mortar with polypropylene fibers indicate an increase of their ductility up to the fiber volume percentage of 0.13%. But then, it seems that further fiber content enhancement has improved its strength, but has reduced its ductility to a lower level.

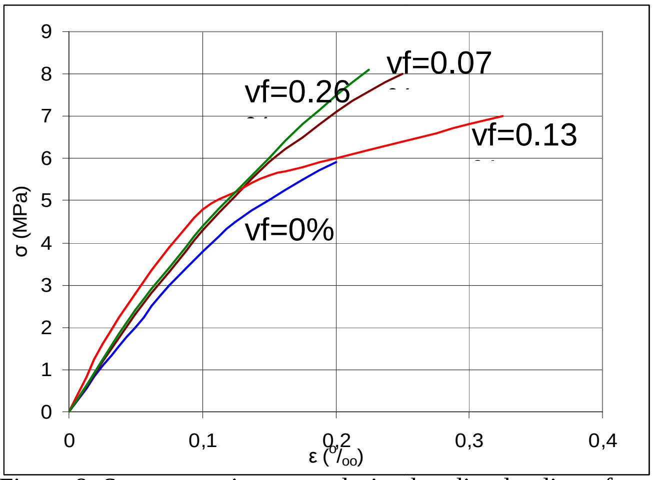


Figure 8: Stress – strain curves during bending loading of mortars reinforced by polypropylene fibers

Conclutions

The fiber-reinforced mortars with polypropylene and glass fibers, that prepared and tested in this study can be used actually as a repairing and supporting materials. As comes by the abovementioned evident, glass and polypropylene fibers reinforce both the compressive and tensile strength of mortars with marble aggregates. Polypropylene fibers also offer an increased toughening in the final product due to their intrinsic ductility in contrast with glass fibers.

B. The study of fiber reinforced and un-reinforced mortar cast specimens, in bending and compression, after their exposure to high temperatures.

In the first series of specimens short polypropylene fibers have been added in a volume ratio of 0.26%, and in the second series glass fibers in the same volume ratio.

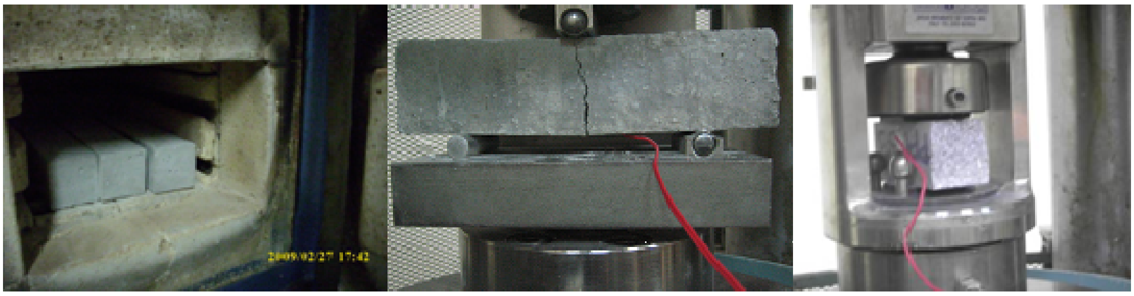


Figure 9: Left: the high temperature furnace used, middle and right: the apparatus for bending and compression loading of mortars, conforming to the standards.

Exposure of specimens at high temperatures

The prismatic fiber reinforced mortar specimens, after their curing completion, were placed in the high temperature oven by triads and heated to the preferred temperature for the corresponding time at rates of 30°C/min up to temperature level of 400°C, falling gradually up to 2°C/min as temperature level was approaching 900°C. Then, they were left to cool gradually within the oven, avoiding any thermal shock, so as to eliminate any cracking from abrupt temperature alterations, with average cooling rate of the order of 20°C/min.

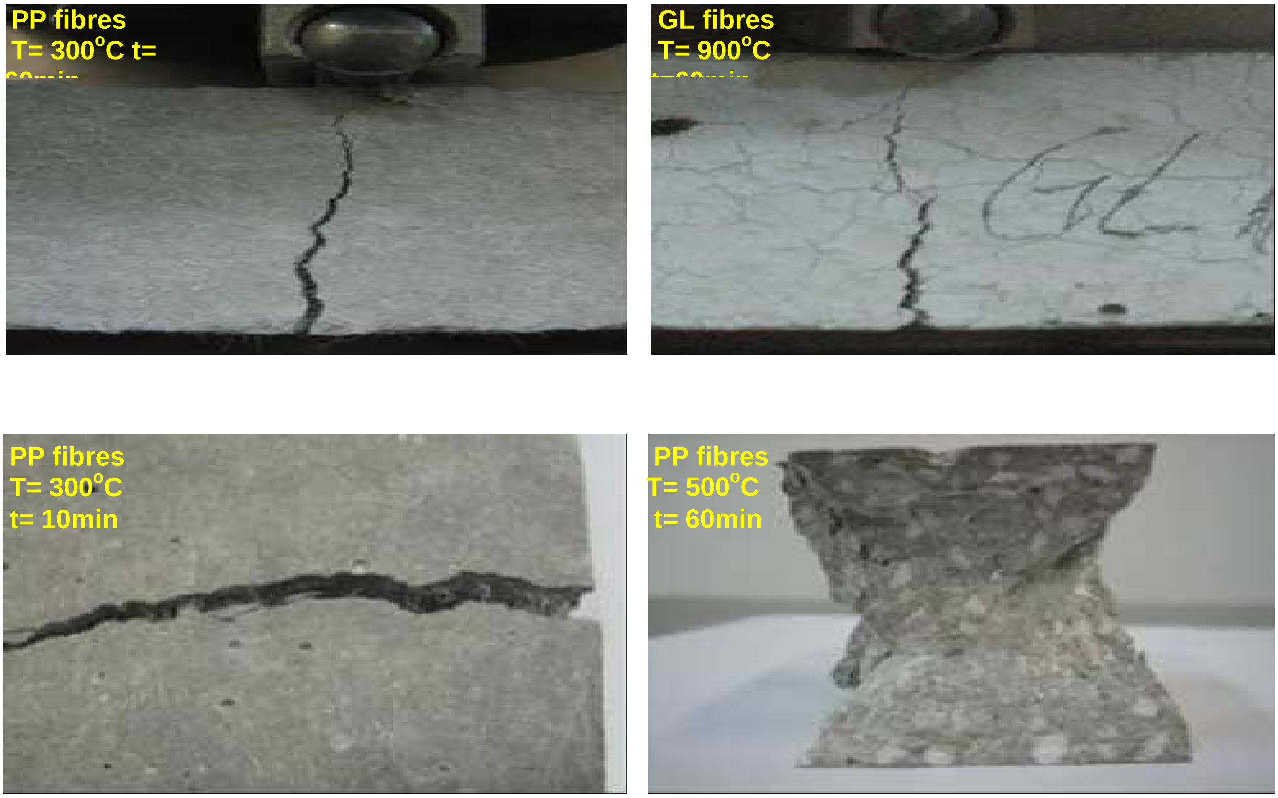
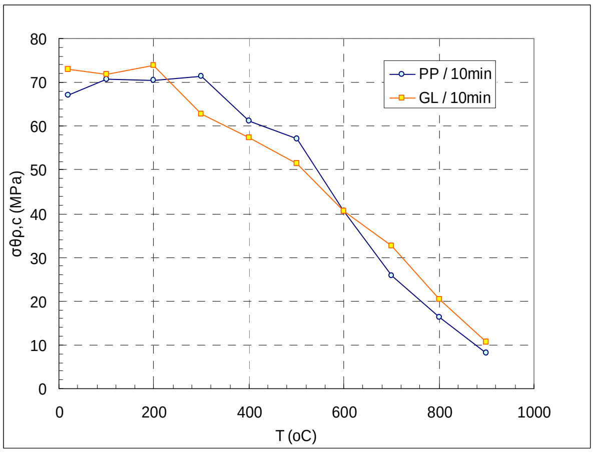
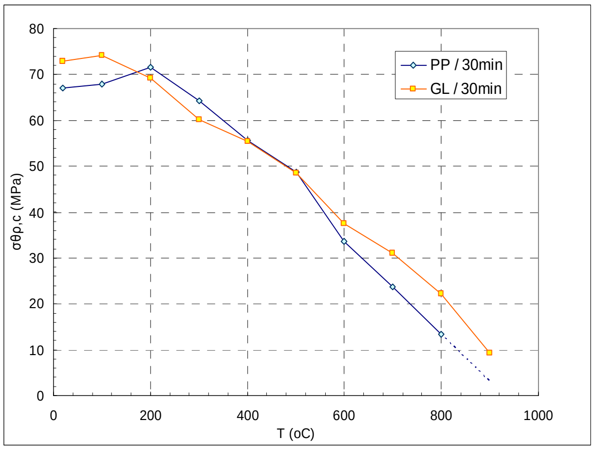


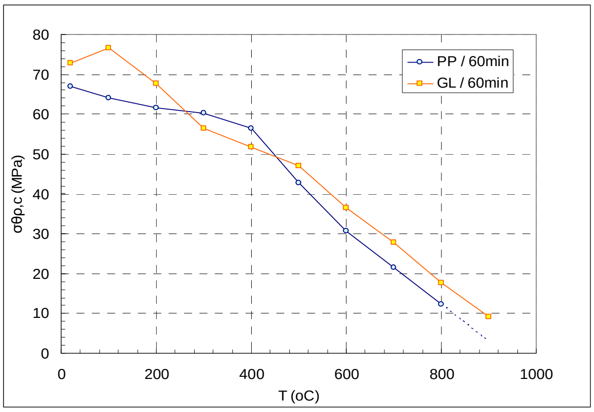
Figure 10: Details of fracture surfaces of specimens after their loading



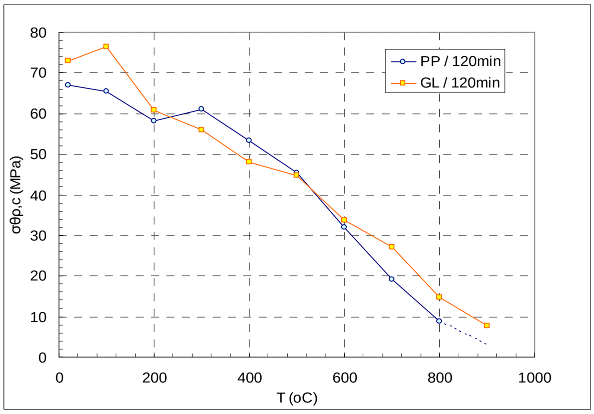
Variation of the compressive strength of reinforced mortars (10 minutes' exposure)



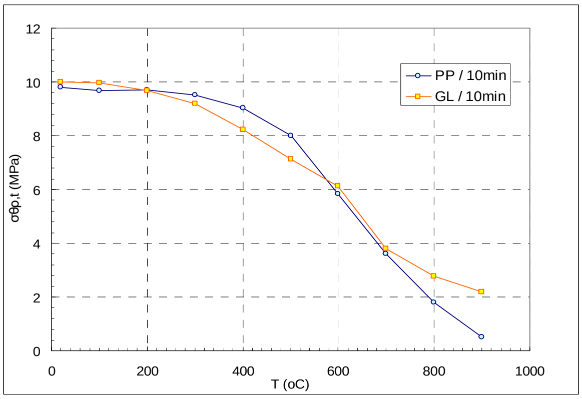
Variation of the compressive strength of reinforced mortars (30 minutes' exposure)



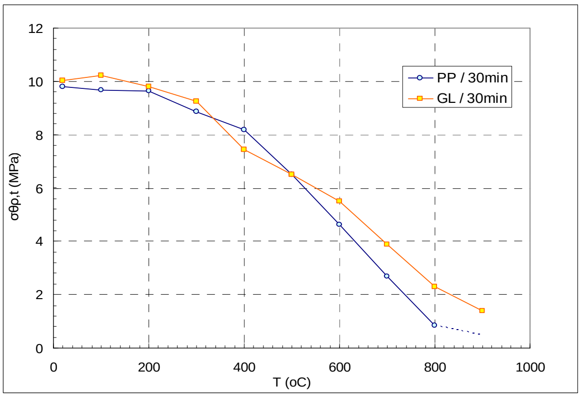
Variation of the compressive strength of reinforced mortars (60 minutes' exposure)



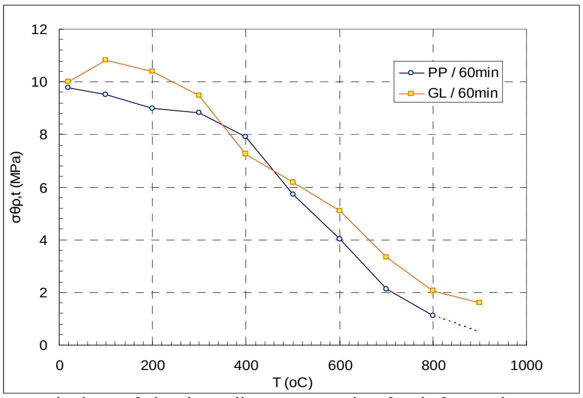
Variation of the compressive strength of reinforced mortars (120 minutes' exposure)



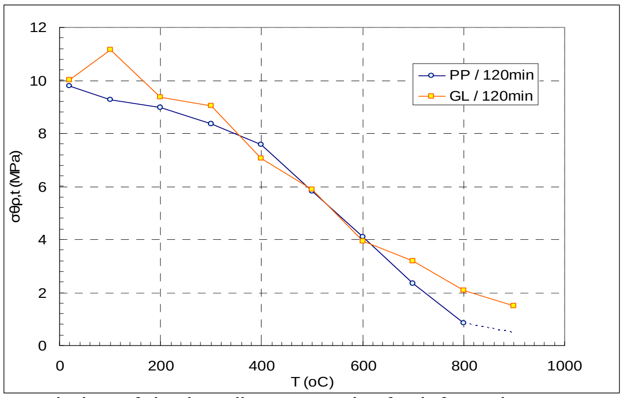
Variation of the bending strength of reinforced mortars (10 minutes' exposure)



Variation of the bending strength of reinforced mortars (30 minutes' exposure)



Variation of the bending strength of reinforced mortars (60 minutes' exposure)



Variation of the bending strength of reinforced mortars (120 minutes' exposure)

FIGURE 11

Bending and Compression Loading

The specimens after their exposure to high temperatures remained in room temperature for a day and were then placed in the specific device for bending loading of mortars. From fracture of the prismatic specimen by three-point bending, two undisturbed ones are produced, which were then tested at compression loading with the help of a corresponding specific apparatus for mortars. The applied load was measured by the help of a loading cell, while for the measurement of strains strain gauges were used along the bottom tensile fibers of specimens, in the case of bending and along height direction of specimens in the case of compression tests.

Evaluation of the results

In the above figures the variation in compressive strength of fiber reinforced cement based mortars for temperature exposure from 100^{o}C up to 900^{o}C and for time exposure intervals of 10min, 30min, 60min and 120min and the corresponding variations for bending strength are displayed. It is obvious that the glass fiber-reinforced, non-heat affected mortars (GL) indicate a compressive strength of about 72,90 MPa (and approximately 10,0 MPa flexural strength), and at the same time the PP fiber-reinforced mortars give slightly smaller values of around 67,10 MPa (or 9,8 MPa flexural strength). More generally, the GL fiber-reinforced mortars show systematically greater strength of around 10% in almost all the temperature ranges and only in the interval between 300^{o}C and 500^{o}C they show a reversion in the appearing strength. The lower strength of the PP fiber reinforced mortars compared to GL fiber reinforced mortars can be attributed to the fact that the PP fibers(~ 2,5 GPa) are much more flexible than the GL fibres (~ 70GPa).

Referring to the PP mortars, the heating of specimens can cause a slight reduction to their compressive strength, which continues to decrease slightly temperature and exposure time increase. When the temperature reaches 400 ^{o}C, the specimens have lost almost 30% of their initial displayed strength.

Afterwards though, for higher levels of temperature exposure the rate of strength reduction becomes more intense reaching almost the10% of its initial strength, as temperature approaches 900^{o}C. (Approximately, 8MPa compressive strength and even below 1MPa bending strength for time exposure of 10min). A corresponding strength variation is observed for glass fibre reinforced mortars, with the only exception of a temporarily strength increase of specimens as temperature approaches 200^{o}C. This observation is also valid for the outcoming bending strength with measured values of about 1/7 of the compressive ones.

The observed strength variation of mortars is due to a combination of procedures that occur inside the specimens due to the increasing of exposure temperature levels. Up to 105 ^{o}C the physically bound water is forced to be removed. Simultaneously and up to 200^{o}C the acceleration of cement curing is favored which can also be observed at the diagrams by the increase of the compressive and flexural strength of glass fiber reinforced mortars. At around 450-500^{o}C the chemically bound water, which comes from the hydration procedure of $Ca(OH)_2$, is also removed. That is why, an intense reduction of the strength of the mortars ia observed in all diagrams in the area of these temperatures, while at the same time the specimens' colour turns into green-grey. Finally, as the temperature of 900 ^{o}C is approached, a chemical disruption of the aggregates occurs together with a simultaneous cracking which becomes even more intense due to the alteration of the thermal expansion coefficient and the very high temperatures, leading to the very low strengths that appear. It is then that the ourof the specimens becomes from grey-white for a short time, up to yellowish as time grows (Ingham 2007).

At the same time, the reinforcing fibres are significantly affected. The polypropylene fibres (PP) melt at about 160^{o}C (Sideri, Manita, Papageorgiou & Chaniotaki 2003) though at about 590^{o}C they get burnt and this might be the reason why the strength introduces a reverse behavior (increase) compared to the one of the glass fibres reinforced mortars among 300 and 500^{o}C. Respectively the glass fibres become smoother (more elastic) at about 800^{o}C producing, as the mixture cools, a more stable material with greater strength that the one with PP fibres, which because of the charring of the burnt PP fibres have obtained increased porosity.

Figure 12: Measuring the strength with the ultrasonic device

Conclutions

The exposure of reinforced cement based mortars to high temperatures relevant to those of a typical fire and for a sufficient time period leads to a downgrading of their mechanical properties. The rhythm of the reduction is low up to 400oC leading to the 30% of their strength and becomes significantly higher then, leading to the 10% of the initial value of strength at 900oC. Measurements of the modulus of elasticity of the specimens by using strain gauges have proved that it reduces dramatically from 32 GPa for not exposure specimens to 1 GPa for specimens exposure to 900oC for 120min, for both GS and PP reinforced mortars. At the same time, testing the specimens with ultrasonic device, has given relevant variations, with a range of values from about 4360m/s (no thermal exposure) to 1270m/s (900oC) for PP fibres reinforced mortars and from about 4450m/s (no thermal exposure) to 1380 m/s (900oC for 2 hours) for GL fibres reinforced mortars. Generally, the measured compressive and bending strength and the observed stiffness are reduced, while on the other hand the indicated strains, the micro crackings, the developed bending deflection and the non linear response get increased in a proportional way.

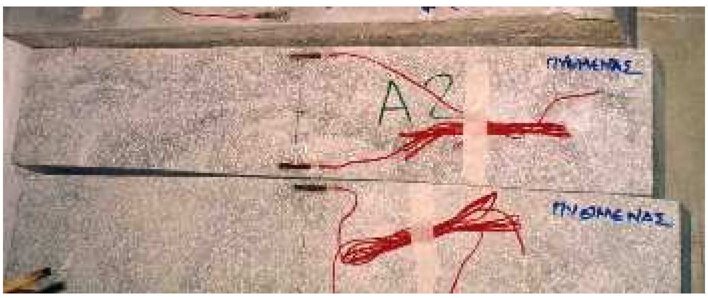
Corresponding tests and diagrams have been carried out for un-reinforced specimens too. The results of the compressive and bending loading lead to the conclusion that the reduction of the specimens' strength due to their exposure to high temperatures, follows precisely the same rhythm for all the specimens, either they are reinforced with GL or PP fibres, or they are un-reinforced.

C. Experimental Research of un-reinforced mortars, cast or sprayed.

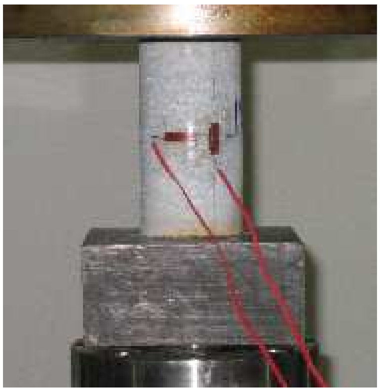
In order to test the as above described specimens in the form of sprayed concrete, panels of sprayed mortar were prepared in the Laboratory out of which specimens of suitable dimensions were cut by using a suitable drill device in specific time periods. Corresponding cast specimens were manufactured and examined collaterally with those of the sprayed mortar, so as to be used as referring material and check the results.

Figure 13: The procedure of spraying mortar into panels under controlled laboratory conditions.

FIGURE 14: Cast specimens into the moulds (left) and cores out off the panels (right)



Specimens for bending loading out of panels



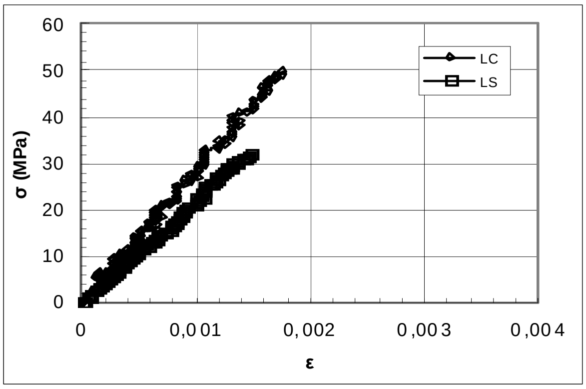
Specimens for Compressive and Tensile tests

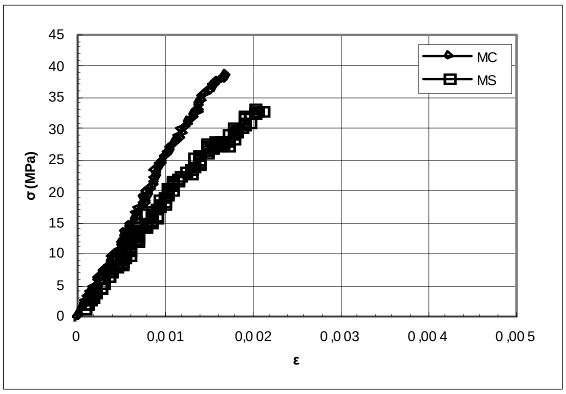
Symmetrical bending test (4 points' test) on specimens taken out off panels of sprayed mortar

FIGURE 15

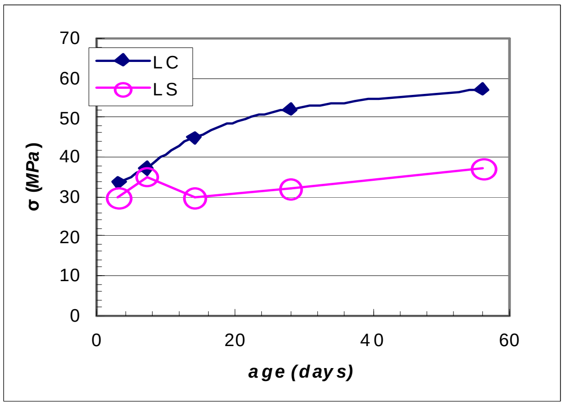
Results

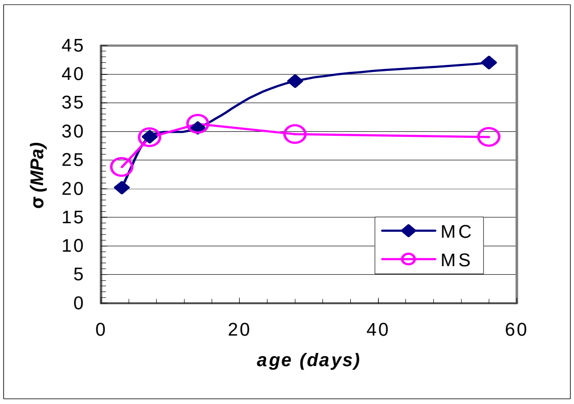
In the following figures a typical stress-strain diagram up to the break point is presented, for both cast and sprayed specimens, with limestone aggregate (a) and with marble aggregate (b), 28 days after their curing. After comparing these two groups of specimens, it is concluded that generally the cast specimens were stronger than the sprayed ones, either with marble or limestone aggregate, while the marble specimens cast or sprayed, never reached the strength of the limestone specimens, with a delay of 10-20%.



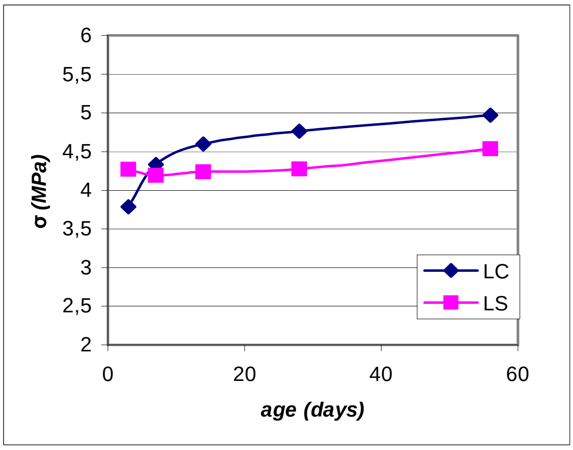


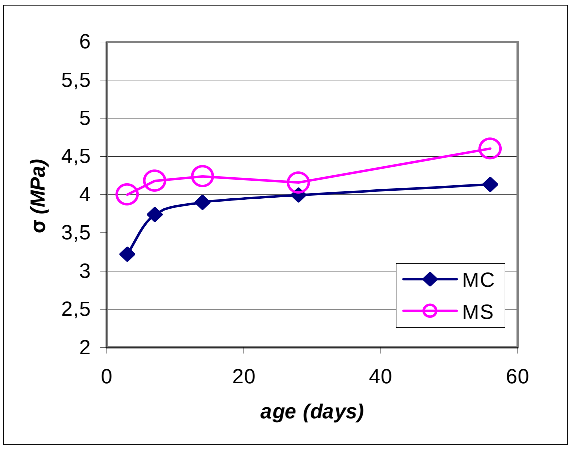
Stress-strain diagrams up to the breaking point, for cast and sprayed specimens, with limestone (left0 and marble (right) aggregates.





Variation of the compressive and bending strength of cast and sprayed specimens, depending on their age (limestone aggregate left and marble aggregate right)





Variation of the tensile strength in Burst rupture of cast and sprayed specimens, depending on their age (limestone aggregate left and marble aggregate right)

FIGURE 16

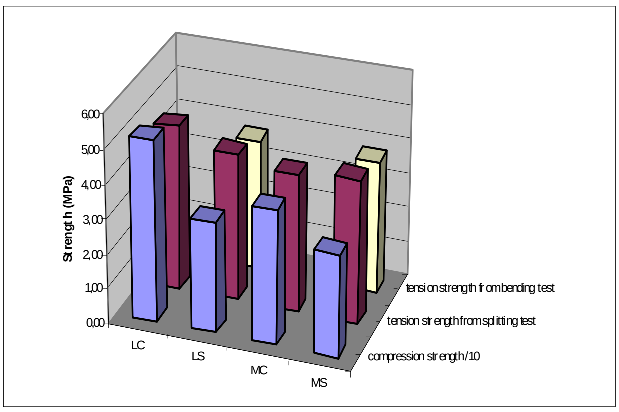
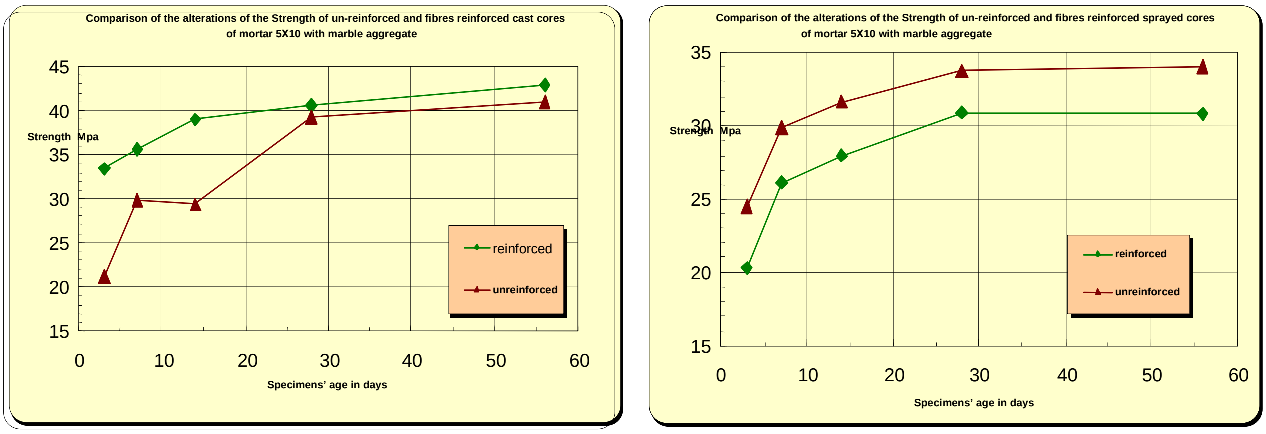


Figure 17: Compressive strength /10, Tensile strength in burst and tensile strength in bending, for all specimens.

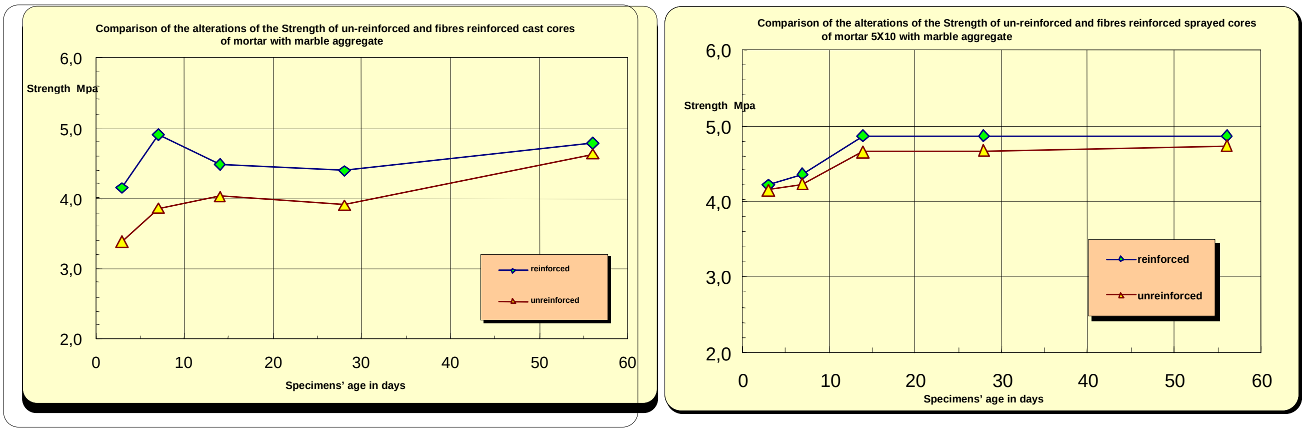
Comparison of the Compressive and Tensile (burst test) strength of fibre reinforced and un-reinforced mortars, both as cast and sprayed ones.

<u>Compressive Strength Figure18</u>



The glass fibres increase slightly the strength of the cast specimens in compression, since by using the proper condensation method, perfect allocation of the fibres into the mass of the fresh mortar is obtained. The small decrease of the strength of the fibre reinforced sprayed specimens compared to the un-reinforced ones is about 10%, and is due to the bad allocation of the fibres into the specimen mass during the spraying procedure. The addition of glass fibres does not affect significantly the compressive strength of both sprayed or cast specimens.

<u>Tensile Strength Figure 19</u>



The fibres increase the tensile strength of cast specimens up to 15% and prevent the opening of wide, destructive cracks.

Concerning sprayed mortar the participation of the glass fibres does not affect significantly the tensile strength, because many factors slip into during the spraying procedure, such as the inadequate wetting of the aggregates, the proper handling of the machinery, the poor coherence due to aggregate rebounds, poor coherence due to the developed layers of spraying etc. get involved. As far as it concerns the crackings though, the fibres function in a preventing way.

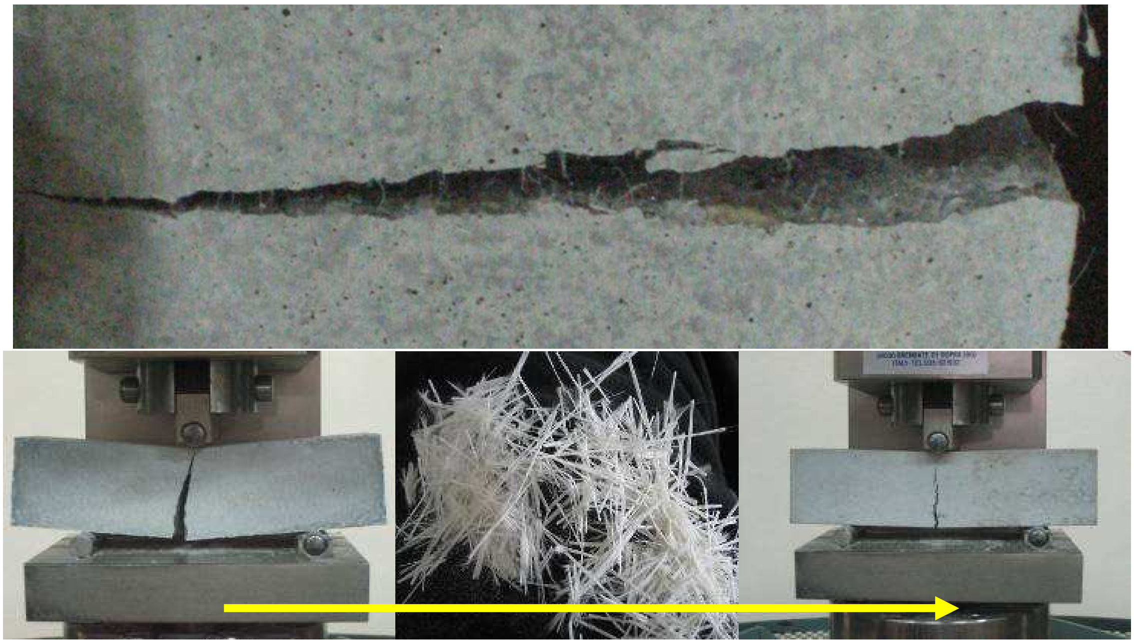


Figure 20: The addition of fibres into the mortar provides it with a more ductile behavior.

Further Suggestions

The investigation of the collaboration of the conventional cement based or lime mortars with insulating materials made of polymers is already progressing while the investigation of more traditional materials under the above described testing conditions is also within the current plans of our Laboratory and research team.

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