Confinement of medium strength concrete cylinders with basalt Textile Reinforced Mortar.

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ABSTRACT: The lack of knowledge and specific regulations during the first half of 20th century led to a generation of concrete structures which do not suit with current standards. Moreover, the use of locally available and, sometimes, inappropriate materials, contributed to decrease the quality and the mechanical characteristics of concrete. Hence, several structures need to be strengthened. The aim of this study is to check the behaviour of a new structural material, named textile-reinforced mortar (TRM), used in jacketing technique in order to improve the performance of concretes with limited resistance capacity. Tests were carried out on basal fabrics and TRM under tension forces and low strength (mud slab) concrete cylindrical specimens. Thirty samples were made using combinations of two mortars for the matrix with different number of plies. Therefore, it can be concluded that TRM is a promising solution in confinement to improve the structural performance of ancient concrete structures.

1 INTRODUCTION

Despite concrete was discovered in the 19th century second half, initial standards did not appear till the first quarter of the twentieth. For a long term a big amount of structures were built with no regulation. Moreover, early standards concerned only the functional aspect of the concrete, with no specifications about quality or durability. In Spain, 1973 standard (EH-73) regulated this matter for the first time. On the other hand, concrete knowledge suffered an important shortage. As it was supposed to be as durable as natural stone, there was no worry about the different materials that were used in concrete elaboration. This situation led to use cheap and available raw materials which, in the long term, proved their no suitability. Beach sand or plain steel are good examples of this inadequate constituents.

These two facts favoured the existence of a concrete with low strength and durability. In order to refer it, the expression "poor concrete" is going to be used. There is no a specific term in which poor concrete can be established accurately. Several factors, besides the previously mentioned, are involved in the problem and it is possible, today, to find concrete with durability problems. Some of these factors are the coastal exposure, lack of covering, high porosity, presence of hollows or the oxidation of the steel.

30 rehabilitation projects, managed by LABEIN-Tecnalia, were studied in order to increase the knowledge about the concrete used in building in the Basque Country before 1960. Moreover, this brief search showed the typical pathologies in this decayed material. Most of the cases showed compression values lower than 15MPa and even specific situations where the compression ultimate stress was 5MPa. Other characteristics are high porosity, more than 17%; high W/C ratio; high chloride content, more than 0.4% of cement; and the carbonisation level reaches the steel so the bars are without passive protection against aggressive agents.

In summary, poor concrete is a common material present in structures built in the first half of the 20th century. Most of these buildings need to be retrofitted, because of the change of the uses, or they do not fulfil nowadays construction codes.

2 CONCRETE CONFINEMENT WITH TRM

2.1 Scenario of the strengthening of RC structures

Confinement is an attractive strengthening or retrofitting solution for reinforced concrete (RC) members in compression. The main aim is to enhance the load carrying capacity and the ductility which can be especially useful in seismic areas. During several years this confinement has been executed with concrete or steel. The use of these materials showed satisfactory results, the rise of compression strength was considerable. But, on the other hand, concrete and steel are heavy materials so the rest of elements have to absorb more load which in some cases forces to upgrade the whole structure.

Fiber Reinforced Polymer (FRP), a light and high specific strength material, solves that problem. Moreover, FRP has an elastic behaviour up to failure so applies a continuously increasing confining action, while steel exerts a constant pressure after the yield point. Some other attractive features, namely, corrosion resistance or easy application, have led FRP to be popular among structural and civil engineers.

Despite these advantages over the traditional methods, the organic matrix and the necessity of adhesives involves several drawbacks such as: destruction in case of fire, poor structural behaviour at temperatures above the glass transition temperature, non-applicability on wet surfaces or at low temperatures, lack of vapour permeability, incompatibility of resins with certain substrates, high cost of resins and adhesives and hazards for the workers.

One solution for the mentioned problems has been the replacement of the organic matrix with an inorganic mortar. Fibres presented a lack of impregnation with the mortar and the necessary adhesion between fibres and the mortar was not achieved. In order to avoid that problem, long unidirectional fibres were replaced by textiles, Triantafillou et al. (2006). Textiles, combined with inorganic (cement-based) mortars led to the composite technology named Textile Reinforced Mortar (TRM). For the last five years textiles and mortars are being developed looking for a good adherence between fibres, mortar and ancient/decayed substrates. For the last years basalt is a raw material which has attained a relevant importance within the world of fibres for construction, already properly applied in masonry stone, Garcia (2009), structures (walls).

2.2 Basalt Textile Reinforced Mortar

Basalt fibres have not been used in FRP systems yet. Basalt fibres have excellent alkali resistance, similar properties to glass, at a much lower cost than carbon or aramid fibres. Basalt is basically a natural material with a melting point of about 1400°C that is found in volcanic rocks all over the world, each with slightly different chemical compositions. It is mainly used in construction, and industrial and highway engineering and is also cast to make moulded parts. Basalt is roughly 5% denser than glass. The elastic tensile modulus of basalt fibers (82-110GPa) is higher than that of E-glass fibers (70- 75GPa). The low elongation, perfectly elastic up until rupture, results in fabrics with high levels of dimensional stability that exhibit reasonable suppleness; drape ability and good fatigue resistance. In application with very low stress on the fibres, temperatures of around +1250°C - the flame temperature - can be sustained continuously without loss of fabric integrity. Because of its thermal insulating properties Basalt fabrics are ideally suited for fire protective applications.

Moreover, basalt fibres have good acid and solvent resistances, surpassing those of E-glass and many other mineral and synthetic fibres. They also have very good resistance to alkalis, while they are slightly less stable than glass in strong acids. Weight loss in boiling water, alkali and acid is also significantly lower for basalt. The inert basic material possesses, in addition to corrosion resistance, good resistances to UV-light and biologic contamination. Absorption of humidity comes to less than 0.1% at 65% relative air humidity and room temperature. Basalt fibres show excellent "wet ability" (or natural adhesion) to a broad range of binders, coating compounds and matrix materials in composite applications. This property can be further enhanced through optimized surface treatment, Häuβler-Combe et al. (2007) and Keil et al. (2008). Above mentioned matters, make basalt fibres and fabrics very attractive for being applied such us a coring reinforcement in composites. In fact, basalt fibres have already been used in flexural strengthening of concrete structures, Brik (1999).

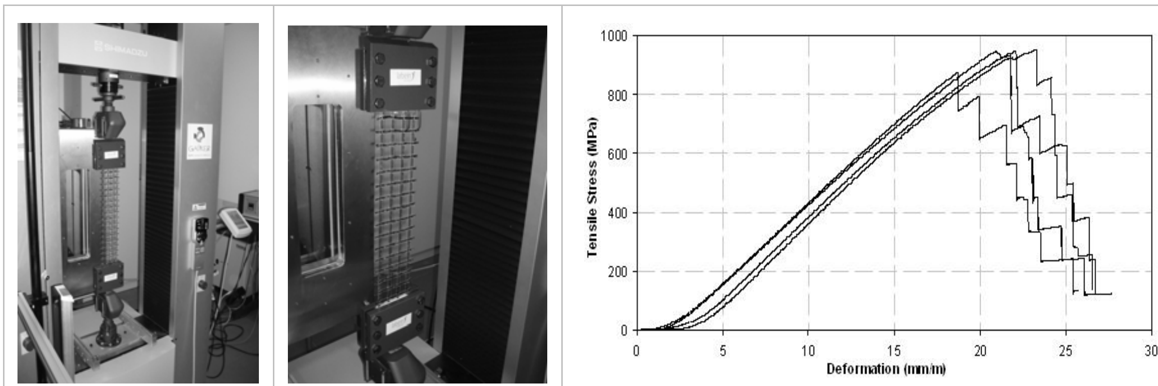
The aims of present paper is to characterize the basalt fabric itself and as a part of TRM. Then check the behaviour of basalt TRM used in confinement of small cylinders made with low quality concrete.

3 EXPERIMENTAL CAMPAIGN

3.1 Basalt textile and TRM characterization

The basalt fabric used in the project has a density of 2750 kg/m^3, a weight of 238 g/m^2 and a cell size 25x25mm^2. These fibres difference from previous ones due to the presence of a bitumen coat which impregnates the basalt rovings and gives them monolithic behaviour enhancing woven's properties. Otherwise the polymeric layer reduces the workability of the fabric, a fact that would be a problem to apply this kind of basalt in certain situations. Two kinds of tests were carried out with basalt. The first one only involves the fabric whereas the second test recorded the behaviour of TRM under pure tensile load.

Basalt fabric test were carried out on ten samples under a Shimadzu 100kN testing machine (see Figure 1 a) with a displacement control of 0,5mm/min. The specimens consisted on four basalt rovings of 800mm long. The ends were soaked in epoxi resin looking for an adequate grip with the testing machine's clamps, so that the tested length was 450mm. The stress-strain relationship of four samples is showed in Figure 1c, whereas in Table 1, the average results, such as maximum load; ultimate strength and strain; and Young modulus, are reported. In order to calculate the value of the tension stress an equivalent thickness of 0.008654mm was used. This value was the result of divide the weight with the density.



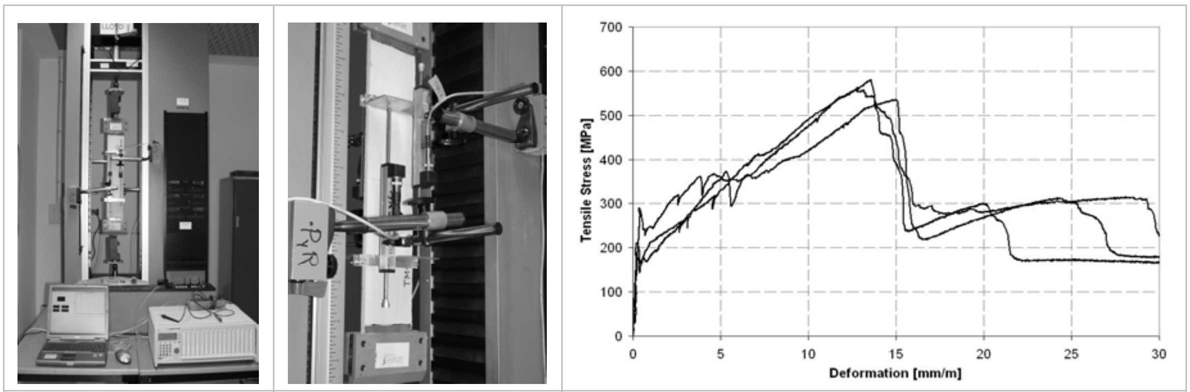
(a) (b) (c)

Figure 1 : Basalt fabric characterization.

Table 1 : Basalt fabric properties.

	P_{max}	σ_u	E_f	ε_{fu}
	[kN]	[MPa]	[GPa]	[%]
Average	3,79	894	52	2,2
COV	0.061	----	0.022	0.096

On the other side, five TRM samples were tested in a Lloyd 5kN universal testing machine. Each sample was a mortar plate with one layer of basalt fabric embedded of 600mm long, 100mm wide and 10mm thick. The length between clamps was 440mm. Due to the characteristics; the strain was measured in the central third part of the specimen (Figure 2b). The testing machine's displacement rate was the same that was used in the basalt fabric test, 0.5mm/min.



(a) (b) (c)

Figure 2 : Basalt TRM characterization under pure tensile loads.

Table 2 : Basalt TRM properties under pure tensile loads.

	P_{max}	σ_u	E_f	ε_{fu}
	[kN]	[MPa]	[GPa]	[%]
Average	2.34	550	27.33	1.29
COV	0.043	----	0.076	0.131

The matrix used in the basalt TRM is a puzolanic mortar Strutturale 1 from Mapei. This mortar was tested at 28 days after casting obtaining a flexural strength of 4.1 MPa and compressive strength of 31.5 MPa. The combination of basalt and mortar, TRM, achieved an efficiency of 61% by comparing with the fabric itself. This fact was affected by the adherence between fibres and mortar.

3.2 Confinement using basalt TRM

An additional purpose of present paper was to investigate the confinement effect of poor concrete with TRM. Moreover, the effect of the number of layers or the use of a different mortar matrix will be investigated in a proper experimental campaign. The investigation was carried out on 30 concrete cylindrical specimens with a diameter of 150mm and a height of 300mm (following the concrete Spanish Code EHE 2008). In order to reproduce the behaviour of poor concrete structures, the specimens were made with low strength (mud slab) concrete, taken from a site civil work where was used as solid ground for pavements. At 28 aged days, the average compressive strength, f_{cm}, was 21MPa. From the remaining specimens, two series of 12 cylinders each one were repaired with TRM. The difference between them was the matrix: puzolanic or cement based mortar. Each series was constituted by six cylinders wrapped with one layer of basalt, and six more samples confined with two layers (see Table 3). Due to the risk of a premature debonding failure an overlap of 120mm length was provided.

Table 3 : Experimental scheme.

	Number of samples			
	Control 28 days	Control 70 days	1 basalt ply	2 basalt plies
	3	3	----	----
Puzolanic matrix	----	----	6	6
Cement-based matrix	----	----	6	6

Referred to mortars issue; the puzolanic one was applied in the TRM tensile test detailed above, while the cement based mortar was done with a volumetric dosage of cement sand and water: 1/3/0.7. After 28 days, the flexural strength was 4.7MPa and the compression strength was 22.4MPa.

The confinement of the cylinders with basalt TRM was done according to four stages shown in Figure 3: 1) concrete's surface wetting; 2) apply the first layer of mortar, 5mm thick; 3) apply the basalt fabric, guarantying a small pretension; and 4) cover the fabric with a second mortar layer with a thickness of 5mm. The basalt fabric, embedded in the samples wrapped with two basalt plies, implies one continuous element.

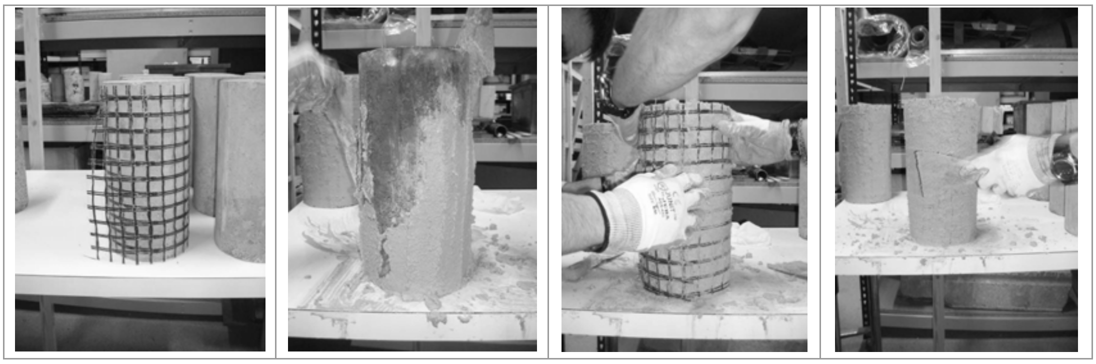
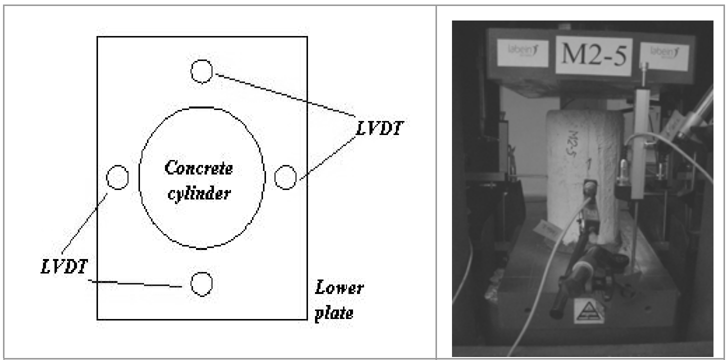


Figure 3 : Concrete confinement procedure

3.3 *Test setup*

Puzolanic mortar series was tested in an Ibertest 3000kN compression machine whose load was applied with a load rate of 0.5MPa/s. The test lay out is presented in Figure 4a. Four ohmic linear variable displacement transducers were placed at ¼ of the cylinder perimeter to measure axial displacement.



(a) (b)

Figure 4 : Compression tests and location of LVDT sensors

On the other hand, the test of the cement based series was performed in a 3R 3000kN, universal compression testing machine. In this case, only the peak strength was recorded.

4 ANALYS OF EXPERIMENTAL RESULTS

Compression tests were executed at 70 days of curing time, so different peak strength was expected. Additionally, three control specimens showed the concrete characteristics at that age: peak strength, f_{co}, and ultimate strain, ε_{cu} (the strain recorded at 95% of the strength peak after it): f_{co}= 21.8MPa, and ε_{cu}= 0.0041.

Results of the performed tests are summarised within Table 4. The ratios between the peak strength of each cylinder and the attained in the control sample are shown, as well as the ratios of the ultimate strain.

Table 4 : Cylinders specimens jacketing with TRM test results

Type	Label	f_{cc}/f_{co}	$\varepsilon_{cc}/\varepsilon_{cu}$
Puzolanic Mortar Series			
One basalt ply	M1-1	1.17	1.24
	M1-2	1.19	1.35
	M1-3	1.26	1.28
	M1-4	1.24	1.34
	M1-5	1.12	1.33
	M1-6	1.23	1.49
Two basalt plies	M2-1	1.34	1.44
	M2-2	1.28	1.38
	M2-3	1.21	1.52
	M2-4	1.14	1.21
	M2-5	1.25	1.38
	M2-6	1.27	1.39
Cement Based Mortar Series			
One basalt ply	C1-1	1.34	-----
	C1-2	1.27	-----
	C1-3	1.37	-----
	C1-4	1.31	-----
	C1-5	1.33	-----
	C1-6	1.27	-----
Two basalt plies	C2-1	1.30	-----
	C2-2	1.26	-----
	C2-3	1.25	-----
	C2-4	1.38	-----
	C2-5	1.32	-----
	C2-6	1.41	-----

The average gains in strength peak and axial strain are reported in Table 5. The scattering of the experiments is characterised by means of the standard deviation (SD) and coefficient of variation (COV). The scattering of the test results was low, showing coefficients of variation between 2% and 6 %. On the other hand, the axial strain presented higher scatter, showing a COV between 6% and 10%.

Table 5 : Cylinders specimens jacketing with TRM. Average results

Type	Strength gain average	SD	COV	Axial strain gain average	SD	COV
Puzolanic Mortar Series						
One basalt ply	1.21	1.12	0.042	1.344	$3.714\cdot10^{-4}$	0.069
Two basalt plies	1.24	1.50	0.055	1.345	$4.926\cdot10^{-4}$	0.094
Cement Based Mortar Series						
One basalt ply	1.31	0.82	0.028	----	----	----
Two basalt plies	1.32	1.44	0.050	----	----	----

The behaviour of the cylinders of the puzolanic mortar series during the test is observed in the stress-strain plots, are given in Figure 5. The shape of these curves was quite similar to that obtained in steel confined concrete specimens which showed three different parts. The first one was an almost linear ascending branch, followed by a second non-linear branch that reached the peak stress point. Finally a descending branch occurred after the peak when the cylinder collapsed. The shape of each branch changed with the number of basalt plies.

The failure stage also gave information; while FRP solutions presented cracks in the hoop direction, Di Ludovico et al. (2008), TRM jacket developed vertical cracks which grew slowly but progressively. When the peak stress point was reached the cracks became wider till the failure moment (Figure 6). The fabric rovings located at the overlap slipped within the matrix in the cylinders retrofitted with one basalt ply, while the samples with two plies presented broken rovings in the overlap area.

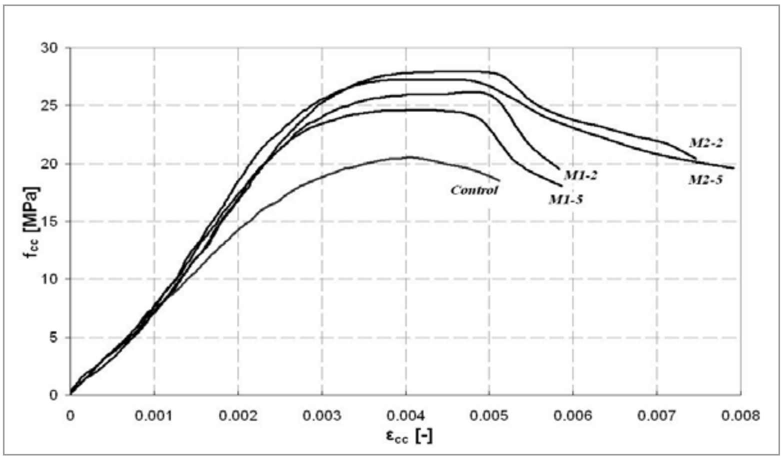


Figure 5 : Stress-strain plots.

(a)	(b)

Figure 6 : Failure mode. (a) Cement-based matrix. (b) Puzolanic mortar matrix.

With all the compiled data some observations are stated. The average gained in terms of strength peak was established between 21% and 32%. This spectrum is due to the use of different mortars for the matrix or the application of different number of basalt plies. Cement based mortar presented higher flexural strength than the puzolanic one. Besides, it was observed how the cylinders wrapped with this material had a higher strength peak than the puzolanic mortar series. On the other hand, the effect of the application of a second basalt layer has not been considerable nor in terms of increasing the strength peak, neither in ultimate axial strain gain, where the average value is 34% bigger than the one achieved in the control samples with one or two basalt plies.

Although the increase to two basalt layers has not improved those values, the strain-stress plots showed in Figure (5) reveals a more ductile failure of the specimens wrapped with two plies. This means that the energy dissipated by the samples of the series M2 was higher than in the series M1. Finally, the graphic confirmed that specimens confined with TRM presented a ductile failure instead the typical brittle collapse of the FRP jackets, Bournas (2007).

5 CONCLUSIONS

TRM is a real solution for those cases where the use of FRP is limited due to the characteristics of the structure of decayed substrates and others in which organic binders are not adequate (hazard, humidity, fire, etc.). Several experiments showed that TRM confining systems achieved a considerable gain in terms of peak strength and axial ultimate strain. This increase is lower than that provided by FRP wrapping, but, on the other side, the failure mode presents a more ductile behaviour.

This paper has provided an additional approach to the use of this promising TRM technology, which its scientific work should be continued. It is obvious that the influence of the matrix, new fibres or different crossed sections should be tested in order to improve the knowledge and look into testing full scale RC columns. In Labein-TECNALIA and Nobatek the work is in progress to make the most of this study and others done before.

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