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Matrix and Fabric Impregnation Influence on Textile Reinforcement Concrete Behaviour

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ABSTRACT: This study aims to analyze the textile reinforced concrete tensile (TRC) behaviour. Firstly A tensile test suitable for this type of cracking material is designed and validated. The second phase aims to highlights the influence of several parameters considered as critical (the material, the thickness of the composite, the impregnation of the fibres, the fibre volume ratio) in the textile reinforced concrete (TRC) behaviour in terms of mechanical performance (strength and stiffness) or the amount of damage correlated with the crack opening measured using image correlation analysis.

1 INTRODUCTION

Repairing structural elements with textile-cement composites is a relatively recent procedure, research on this material having begun in the mid-90s (Ohno & Hannant 1994, Peled et al. 1994). Work done to characterise the composite concentrated on its behaviour under tension and various procedures for characterising tensile strength were established. Characterisation in pure tension (Jesse 2004, Hegger et al. 2005, Mobasher et al. 2005) was preferred to flexion (Peled & Bentur 2000), for the latter, owing to the unknown position of the textile in the thickness of the composite as well as the unknown behaviour of the textile-cement composite in compression, was not thought to be appropriate for this type of material.

In the studies already carried out on the behaviour of textile-cement composites in pure traction, the stress-strain curve was usually divided into three zones. The first zone (Zone 1) is linear as seen in (RILEM TC 201-TRC members), and in the ACK model (Aveston et al. 1971), or quasi-linear (Mobasher et al. 2005). At the transition between zones 1 and 2 there is a sudden change in rigidity, linked (Hegger et al. 2005) to the initiation of the first crack in the cement. Zone 1 is then followed by a zone of non-linearity in which the rigidity is much lower and can present considerable oscillation (Zone 2); the rigidity of the third, linear, zone is greater than in the second zone but lower than in the first (Zone 3).

In any case, the quantitative aspect of the tension-strain curve is subject to wide variations depending on such factors as the strength of the fibres and the cement, the proportion of fibres, the type of fibre and of cement (adhesion at the fibre-cement interface, impregnation of the fibres etc.), the configuration and orientation of the textile… Many studies have been undertaken on the influence of the various parameters of textile-cement; however, most of them were of an exploratory nature and presented a very limited number of tests which led to somewhat tendency conclusions.

The present experimental study is a part of an important experimental campaign that we will undertake to provide experimental information on textile-cement composites and to allow the construction of reliable analytical models. The study involves 14 configurations of composites and its main objectives are to analyse i) the influence of ratio reinforcement on composites of different textile configuration, ii) the influence of matrix nature on the tensile behaviour, and iii) the influence of the roving configuration and roving impregnation used in textile reinforcements of identical mesh on the mechanical behaviour of the composite under tension. To this end, a methodology for comparing the key parameters of stress-strain curves was established.

2 COMPOSITES CONFIGURATION

2.1 *Fabric and matrix*

Tow dissimilar matrix are test in this study i) a thixotropic fine grained concrete (maximum size of 1.25 mm) matrix (TC) alloying contact-moulded “in situ” procedure and ii) a fluid consistency inorganic phosphate cement (IPC) (Promis et al. 2010) adapt to plate prefabrication process. The suplier's characteristic of TC matrix are 8 MPa for flexion strength and 17.6 GPa for E-modulus.

The textile was a warp-knitted fabric with a mesh size of 3 x 5mm (5 mm between weft roving). The only variable in the textiles was the configuration of the roving (Table 1) in the direction of tension of the composite (i.e. in the weft). The warp yarn was a 2200 Tex high-strength polyester (PET).

Table 1. Technical characteristics of reinforcements

Fabric nature	Fibre per roving	Roving titer (Tex)	Diameter of fibre (µm)	Supplier strength of roving "σ_f"(Mpa)	Supplier E-modulus of roving "E_f"(Gpa)
Basalt	4598	1680	13	1835	84
AR-glass	1600	1200	19	1102	74

2.2 *Textile reinforced concrete composite*

Table 2 shows the composite configurations retained. According to (Häußler-Combe & Hartig 2007, Krüger et al. 2002, Krüger 2004) deeper is the fibre position in the roving, worst is the impregnation. So, in a roving, only very few filaments have a perfect bond quality (Hegger et al. 2005). Fabric impregnation could improve transfer of bond stress among fibre. To test this, composites' fabrics are impregnated with epoxy (E3ep) and with synolit (E3sy).

Table 2. Composite configuration

Name	Thickness of composite (mm)	Fabric nature	Matrix nature	Number of Fabric per composite	Roving volume ratio (‰)
B1*	5	Basalt	TC	1	19.5
B2*	5	Basalt	TC	2	39.1
B1	10	Basalt	TC	1	9.8
B2	10	Basalt	TC	2	19.5
B3	10	Basalt	TC	3	29.3
B4'	5	Basalt	IPC	4	
E1*	5	E-glass	TC	1	14.5
E2*	5	E-glass	TC	2	29.1
E1	10	E-glass	TC	1	7.3
E2	10	E-glass	TC	2	14.5
E3	10	E-glass	TC	3	21.8
E4'	5	E-glass	IPC	4	
E3ep	10	E-glass	TC	3	21.8
E3sy	10	E-glass	TC	3	21.8

2.3 *Tensile test description*

The test specimens used for the characterisation of the textile-cement composites under pure tension consisted of a plate of contact-moulded composite material (5 or 10 x 100 x 500 mm) and aluminium lugs (4 x 100 x 100 mm) bonded (sand-blasting + epoxy glue) to the four extremities of the plate. Tension was applied to the extremity of a metal cylinder placed across the lugs of the previously drilled specimen (Figure 1). Specials more were developed to applied pure axial tension (Figure 2). As in a previous experiment (Jesse 2004), two extensometers (measuring zone - 200 mm) were bonded with flexible glue on the middle of each side of the specimen (Figure 1). Other authors prefer to measure the space between the aluminium lugs (Singla 2004, Hegger et al. 2005, Hegger & Voss 2008), probably in order to record the post-peak behaviour; however, this measurement integrates, in the average strain, any possible perturbations caused by the aluminium lugs. (Hegger et al. 2005) considers a measurement zone of 400 mm, but, given the maximum spacing between the cracks of 20mm that was noted (Hegger et al. 2005, Mobasher et al. 2005), a zone of 200 mm was deemed sufficient. The homogenised stress of the composite is obtained by dividing the tensile-force by the section of a composite sample. The average strain is calculated by averaging the displacements measured for the two faces of the sample, and then dividing this value by the length of the LVDT measuring zone.

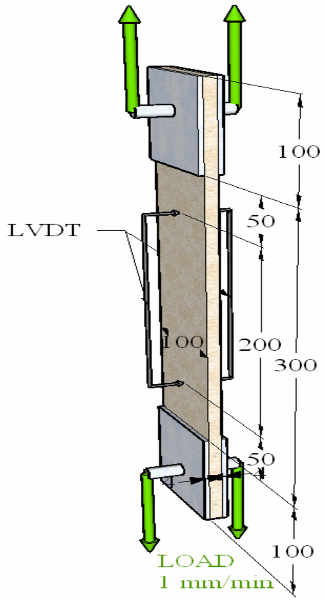

Figure 1. Tensile specimen (geometry, instrumentation and loading)

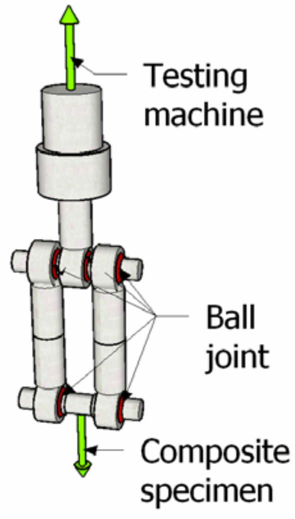

Figure 2. Tensile specimen (geometry, instrumentation and loading)

3 RESULTS

As noted in the review of the literature in introduction, the stress-strain curves obtained in our series of experiments present three zones. To facilitate the comparison of these curves, three characteristic points between each of the zones and at the point of ultimate constraint have been defined (Figure 3).

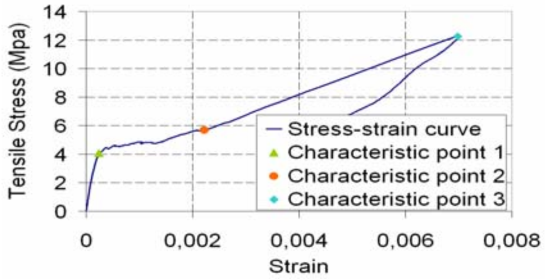

Figure 3. Qualitative comportement type of stress-strain curve and characteristic point position.

Many results were collected during this study, such as the relationships between the volume ratio of fibre reinforcement in the direction of tension and the following values: stress at characteristic point 1, the stiffness of zone 1, the range of strain in zone 2, the stiffness in zone 3, the spacing of cracks at failure and the strength and ultimate strain of the composite. In the interests of concision, only the results involving strength and stiffness in zone 3 are presented.

The final stiffness of composites is defined by the slope of the stress-strain curves in zone 3 (linear zone). This slope is calculated by the method of least squares between the characteristic points 2 and 3. The curves of composite final stiffness as a function of reinforcement volume (for an identical roving configuration) are linear and their prolongation passes through the origin (Figure 4). Similarly, the composite strength seems to be directly proportional to the composites’ reinforcement ratio (Figure 5).

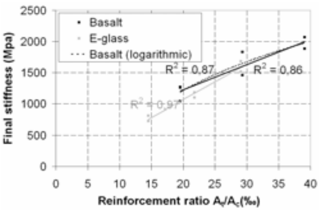

Figure 4. Composite final stiffness-reinforcement ratio linear tendency curves

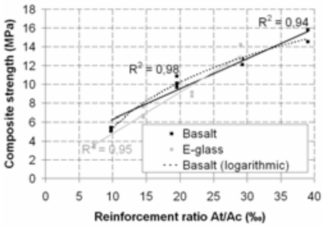

Figure 5. Composite strength-reinforcement ratio linear tendency curves

These results should be qualified, since, with no reinforcement, the strength and stiffness would be that of the matrix. There is, therefore, as a function of the textile and matrix configurations, a threshold level of reinforcement below which the preceding relationships are not valid. Also, for a more important reinforcement ratio (1 - 3 %) Hegger at al. (Hegger at al. 2005) show that for similar type of fabric and fine grained concrete the composite, tensile strength of textile decrease with increasing reinforcement ratio. So, there is probably an other threshold level of reinforcement above which the preceding relationships are not valid. This could mean that above a threshold (that depend of matrix and roving configuration) layers influence each other and cause reduction in bond performance. This is probably the reason for light nonlinearity observed for Basalt roving. This relationships agree with the ACK model (Aveston et al. 1971) which considers that strength "σ_c" and final stiffness of composite "E_c" are proportional to fibre ratio "f". Comparison of the experimental results with the ACK model ($E_c = E_f . f$ et $\sigma_c = \sigma_f . f$) shows that the model overestimates the mechanical characteristics of the composite. As the ACK model considers that all the fibres work in a homogenous way until failure, it is interesting to calculate the fibres' rate of work "T_{fE}" and "$T_{f\sigma}$" using this model (with $E_c = E_f . f. T_{fE}$ and $\sigma_c = \sigma_f . f. T_{f\sigma}$). It then appears that the work level calculated using the rigidity relationship is significantly greater than that calculated using the relationship of composite strength (Table 3)

Table 3. Taux de travail en rigidité et résistance

Configuration	E_f / f (GPa)	σ_f / f (MPa)	T_{fE} (%)	$T_{f\sigma}$ (%)
B	54	472	65	26
B4’	62	697	74	38
E (reference)	54	466	74	34
E4’	63	650	87	47
E3ep	52	640	72	46
E3sy	53	379	73	27

This divergence between the ACK model and the experimental results in strength is probably linked to failure obtained by the textile slipping through lack of anchorage or by a state of non-homogenous stress in the roving. Indeed, ACK model consider a perfect bond of the roving, but according to (Häußler-Combe & Hartig 2007, Krüger et al. 2002, Krüger 2004) deeper is the fibre in the roving, worst is the impregnation. This state of non-homogenous impregnation leads then to great stress concentration (near to the aluminium lugs and out of measurement zone) (Figure 6) leading to premature failure of outer roving’s fibres, slipping of central roving’s fibres and then failure of composite.

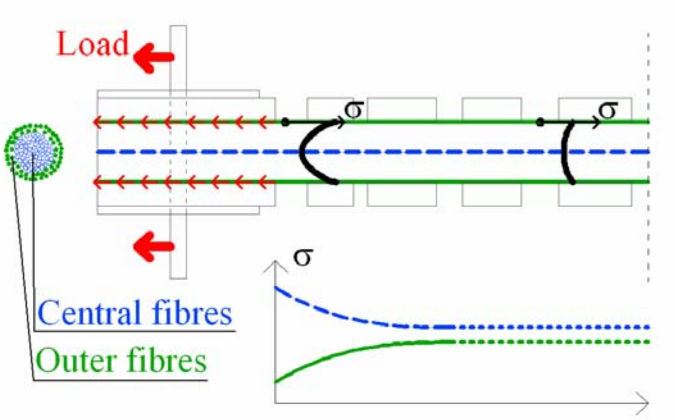

Figure 6. Roving’s fibres stress distribution in a composite specimen.

On the other and, thanks to central fibres bond, further from the aluminium lugs roving is, more homogenous the stress is (Figure 6). Textile slipping through lack of anchorage or homogenisation of stress across the roving explain the divergence between the work level calculated using the rigidity and the strength relationship. So it seems pertinent to retain, even as merely an approximate indicator of the ratio of fibres mobilised in the TRC, the ratio resulting from the calculation of the levels of work in rigidity.

Synolit impregnation of fabrics decrease "$T_{f\sigma}$". A slip of roving were experimentally noticed. So, bond between mortar and synolit is probably smaller than between mortar and rovings. On the contrary epoxy impregnation improve "$T_{f\sigma}$". This is most likely due to a better stress distribution inside roving thanks to epoxy. On the other side, epoxy impregnation don't improve "T_{fE}". So like it is showed Figure 6 in the LVDT measurement zone stress is probably uniform inside the roving, even without impregnation. Impregnation seems useless to improve stiffness in the LVDT measurement zone. When IPC matrix is used, improvement of "T_{fE}" is likely due a better stress repartition among fabric. Increase of "$T_{f\sigma}$" is probably due to a deeper matrix penetration inside the roving. At last, "T_{fE}" and "$T_{f\sigma}$" are better for E-glass than for Basalte. This is due to a better bond of E-glass with TC and IPC matrix and to a better matrix penetration in E-glass roving thanks to a smaller fibres number per roving and a wider fibres diameter.

4 CONCLUSION

The procedure retained for the characterisation of TRC in traction proved effective. Low dispersion (less than 7%) was observed between the stress-strain curves.

It has been shown in this study that the strength of TRC depends on the surface available to the textile, that is, the surface in contact with cement. A linear correlation has been established between the final stiffness (and strength) of the TRC and the ratio volume of useful fibres (those in the direction of the load). The work level of the fibres as calculated with the ACK model varies according to the parameter calculated (the composite's final stiffness or its strength). It seems more pertinent, in view of the occurrence of failure through lack of anchorage, to calculate the quantity of filaments actually under load by using the level of work on the basis of the final rigidity of the TRC.

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