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BOND ANALYSIS BETWEEN FIBER REINFORCED POLYMERIC COMPOSITES AND CLAY MASONRY BLOCKS

BY

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Abstract. Masonry structures have been used ever since the dawn of construction, and nowadays, due to structural inadequacies, material degradation caused by aging, and alterations carried out during use over the years, elements often need strengthening to re-establish or improve their performance. All designers seek efficient solutions; requirements which fiber reinforced composite strengthening systems can be designed to meet. In this frame, fibre reinforced polymeric composites (FRP), used as external reinforcement bonded to the masonry substrate, can be a competitive strengthening solution if they comply with the cultural value of the building. One of the most important aspects when strengthening masonry elements using FRP materials is the bond between the composite reinforcement and the substrate, which influences in a great extent the performance of the strengthened member. Actually, a premature and brittle failure at the interface, called *delamination*, can occur compromising the overall structural response. In the literature, many research projects that study the bond between FRP sheets and concrete were developed, while in case of masonry substrates there are many fewer experimental results available. This paper

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presents the results of an experimental analysis on bond behaviour between FRP sheets (of different types and dimensions) and masonry substrate, using shear test setup. The obtained results are presented and discussed.

Key words: bond; FRP; masonry; delamination; strengthening.

1. Introduction

The need of strengthening masonry structures became an important issue in the field of civil engineering. Currently, concerning this matter, there is a worldwide awareness of the use of fibre reinforced polymeric composite (FRP) materials (Cosenza *et al*., 2000; Nart, 2003; Foraboschi, 2004; Ceroni & Prota, 2009). The proper use of composites as reinforcement for masonry structures is governed by the knowledge of the mechanical behaviour of reinforced masonry system, with particular reference to the failure modes that emerge due to a detachment of the reinforcement from the masonry support, since in this case the failure mechanism is a brittle one and should therefore be avoided. Thus, the key factor characterizing the mechanical behaviour of the FRP – masonry system is the bond strength, namely the maximum load that can be transferred from the masonry substrate to the composite material (Briccoli *et al*., 2009).

Various researchers performed experimental tests on FRP strengthened masonry elements subjected to bending and noticed that the tested specimens developed a premature failure due to FRP delamination from the masonry substrate (Ehsani, 1995, 1997, 1998, 1999; Laursen *et al*., 1995; Schwegler, 1995). The results confirmed the importance of the bond behaviour in order to provide an optimum adhesive joint, which was previously observed for concrete substrate (Maeda *et al*., 1997; Bizindavyi & Neale, 1999; Aiello & Pecce, 2001).

2. Experimental Program

2.1. Test Setup

The experimental program involves testing FRP – masonry samples (282 × 240 × 115 mm), consisting of four full ceramic bricks, made of burnt clay (Fig. 1), using a 1,000 kN universal testing machine. The load was applied with a constant displacement rate of 0.2 mm/min.

Taking into consideration the instructions provided by the manufacturer, a 50 mm wide FRP strip was applied on one side of the specimen. Variations of the bonded length, type and width of composite strip were performed.

The specimens were grouped in two main groups, depending on the type of composite strip; therefore, glass fibres reinforced polymeric composites (GFRP) and carbon fibres reinforced polymeric composites (CFRP) were used, the labels utilized for them being MG and MC, respectively. Within each group three new series were realized, depending on the bonding length, namely: 10, 15 and 20 cm, having as label extension 1, 2 and 3, respectively. In addition to these groups of samples another set was made, for which a 25 mm wide GFRP strip with a bonded length of 10 cm was used, having the label MG1′.The tested specimens summed up to a total of 21 specimens tested to a single shear test.

Fig. 1 – Test set-up.

During the specimens manufacturing, the saturation of the ceramic blocks was considered, thus a 24 h immersion in water was realized. When placing the bricks, 8 mm spacers were used; however the thickness of the mortar joints varies between 8 mm and 12 mm, being generally of 10 mm.

In order to improve the bond behaviour, the substrate preparation was performed by grinding and vacuuming dust and removing oil, grease or other unwanted compounds. Furthermore, with the same purpose, a primer was applied on the surface that the composite strip was to be bonded. The next step consisted in applying unidirectional GFRP strip impregnated with epoxy resin.

2.2. Materials Used

a) *Ceramic blocks*

The ceramic blocks used within the experiment are full bricks, made of burnt clay, mostly used for masonry structures, with the dimensions of 240 × × 115 × 63 mm, and having the properties specified in Table 1, according to the technical data provided by the manufacturer. The grout joints were made utilizing a cement mortar mix, commercially available, that meets the requirements of EN 998-2 (2004). The cement mortar mix was prepared using a stirring mixer, its properties being specified in Table 1.

Table 1
The Characteristics of the Masonry Blocks

Ceramic block	
Average compression strength a) perpendicular on the exposed face, [N/mm^2] b) perpendicular on its end, [N/mm^2]	 45 10
Initial shear strength, [N/mm^2]	0.42 / 0.48
Water absorption, [%]	15
Equivalent thermal conductivity, [W/m.K]	0.435
Cement mortar mix	
Maximum grain, [mm]	3
Compressive strength (28 days), [N/mm^2]	>5
Tensile strength in bending, [N/mm^2]	> 1.5
Density	≈ 1,850

b) *Composite strips*

The strips utilized within the current experiment are unidirectional fabrics made of glass or carbon fibres, with a width of 55 mm and their length varying with the bonding length. In Table 1 are listed the FRP properties and characteristics according to the data sheet. When applied, special care was paid to the fibre impregnation (Fig. 2).

Fig. 2 – Applying the FRP strips on the masonry substrate.

The adhesive that facilitated the bonding of the FRP strips on the masonry substrate was an epoxy adhesive Sikadur 330, for which the instructions provided by the manufacturer were strictly followed. Sikadur 330 is a bi-component structural adhesive, whose main physical and mechanical properties can be observed in Table 2. The two components were mixed for approximately 3 min. with a low speed drill press, until the material became homogeneous.

Table 2
Main Characteristics of the Composites

Products characteristics	Values given by the manufacturer
Glass fibers fabrics SIKA Wrap 430G	
Tensile strength, [N/mm^2]	2,300
Elasticity modulus, [N/mm^2]	76,000
Thickness of the fibres, [mm]	0.17
Elongation to failure, [%]	2.8
Carbon fibers fabrics SIKA Wrap 230G	
Tensile strength, [N/mm^2]	4,300
Elasticity modulus, [N/mm^2]	238,000
Thickness of the fibres, [mm]	0.13
Elongation to failure, [%]	1.8
Epoxy adhesive SikaDur 330	
Compressive strength (7 days), [N/mm^2]	30 (at +23°C)
Elasticity modulus (7 days): a) to flexure, [N/mm^2] b) to traction, [N/mm^2]	a) 3,800 (at +23°C) b) 4,500 (at +23°C)
Elongation to failure (7 days), [%]	0.9 (at +23°C)

2.3. Test Results

For all tested elements the failure modes were generally similar (Fig. 3), namely the failure occurred by debonding the FRP strip from the substrate. Moreover, it was noticed that the delamined surface included a considerable thick layer of masonry.

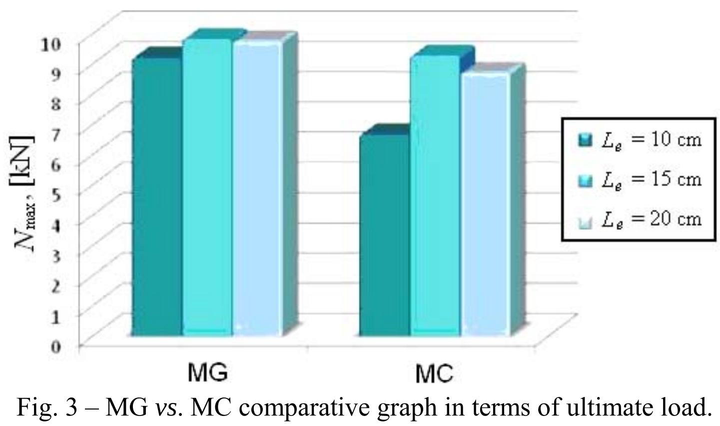

Fig. 3 – MG *vs*. MC comparative graph in terms of ultimate load.

The results for all seven series are reported in Table 3, in term of ultimate load ($N_{fa,\max}$) and maximum displacement ($s_{f,\max}$). The series were realized in such a manner that the target parameters can be analysed, namely the influence of the type of fibre, bonded length and strips width. Thus, for the assessment of the target parameters, the results were compared between them. In Fig. 3 are illustrated the ultimate force average values depending on the type of fabric applied at various bonded lengths. Analysing this graph it can be noticed that the bonded lengths greater than 100 mm do not have a major influence on the ultimate load. Also, on the same graph it can be seen a slightly higher value for the average maximum load of the specimens bonded with fibre glass strips, but nevertheless the influence of the type of FRP is relatively small (Oltean *et al*., 2011).

Table 3
Summarized Test Results

Specimens series	Specimens label	Strips width mm	Bonded length, [mm]	$N_{fa,\max}$, [N]	$s_{f,\max}$, [mm]
MG1	MG1_1	50	100	7,820	6.1
	MG1_2	50	150	9,200	4.2
	MG1_3	50	200	10,600	4.8
MG1′	MG1′_1	25	100	6,250	5.1
	MG1′_2	25	150	7,080	4.7
	MG1′_3	25	200	4,080	2.8
MG2	MG2_1	50	100	9,950	3.9
	MG2_2	50	150	9,900	5.0
	MG2_3	50	200	9,630	5.3
MG3	MG3_1	50	100	9,800	5.8
	MG3_2	50	150	9,070	3.3
	MG3_3	50	200	10,400	5.5
MC1	MC1_1	50	100	7,440	4.4
	MC1_2	50	150	6,770	3.5
	MC1_3	50	200	5,820	4.6
MC2	MC2_1	50	100	8,730	4.7
	MC2_2	50	150	8,700	5.3
	MC2_3	50	200	10,400	6
MC3	MC3_1	50	100	9,120	5.7
	MC3_2	50	150	8,380	4.4
	MC3_3	50	200	8,660	4.9

However, the same remark can not be made in terms of reducing the width of the composite strip to half (Fig. 4). In this case the average ultimate strength showed a decrease from 9.2 kN to 5.8 kN, representing a decrease with 37%.

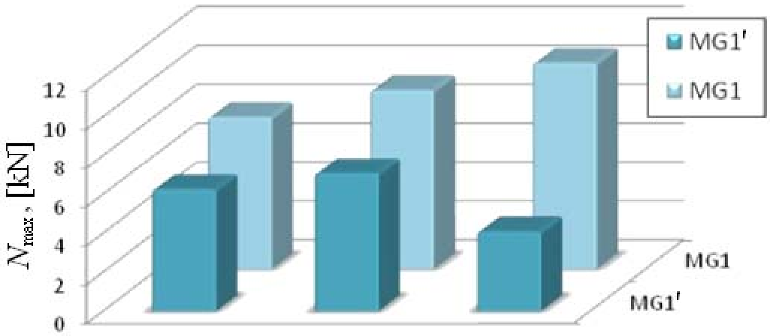

Fig. 4 – MG1 *vs*. MG1′ comparative graph in terms of ultimate load.

4. Conclusions

The study of the structural performance of FRP – masonry bonded joints became quite complex due to the multitude of parameters involved, which affect the bond behaviour. In this paper is presented an experimental program based on single shear test and performed on hybrid FRP – masonry specimens. Debonding of the FRP strips from the surface of the substrate represents the most common failure mode in all studied cases. The failure at the interface occurred in the substrate and had a brittle manner. Therefore, it can be stated that the shear strength capacity of the substrate material is a major parameter of the interface region behaviour. Also, the type of FRP composite seems to have a limited effect on the ultimate load.

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STUDIUL CONLUCRĂRII DINTRE COMPOZITELE POLIMERICE ARMATE CU FIBRE ŞI BLOCURI DE ZIDĂRIE CERAMICĂ

(Rezumat)

Structurile din zidărie au fost utilizate încă de la începuturile construcţiilor, iar în zilele noastre, ca urmare a deficienţelor structurale, a degradărilor materialului datorită îmbătrânirii, şi a alterărilor apărute pe parcursul exploatării, elementele necesită deseori consolidări pentru restabilirea sau creşterea performanţei acestora. Toţi proiectanţii caută soluţii eficiente; cerinţe la care pot răspunde sistemele de consolidare cu materiale compozite polimerice armate cu fibre. În acest cadru, compozitele polimerice armate cu fibre (CPAF), utilizate ca armătură exterioară aplicată pe substratul de zidărie, pot constitui o soluţie competitivă de consolidare, cu condiţia ca acestea să fie conforme cu valoarea culturală a clădirii. Unul dintre cele mai importante aspecte în consolidarea elementelor din zidărie cu materiale CPAF îl reprezintă conlucrarea dintre armătura compozită şi substrat, care influenţează într-o mare măsură performanţa elementului consolidat. De fapt, cedarea prematură şi fragilă la nivelul interfeţei, numită *delaminare*, poate avea loc şi poate compromite răspunsul structural per ansamblu. În literatura de specialitate, au fost dezvoltate mai multe proiecte de cercetare care studiază legătura dintre fâşiile CPAF şi beton, în timp ce în cazul substratului de zidărie sunt disponibile mult mai puţine rezultate. În lucrare se prezintă rezultatele unei analize experimentală a conlucrării între fâşii CPAF (de diferite tipuri şi dimensiuni) şi substratul de zidărie, folosind configuraţia încercărilor la forfecare. Rezultatele obţinute sunt prezentate şi discutate.