MECHANICS OF MASONRY STRUCTURES
strengthened with composite materials
Modeling, testing, design, control
Ravenna (Italy), 9-11 September 2014

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Experimental study of the bond of FRP applied to natural stones and masonry prisms

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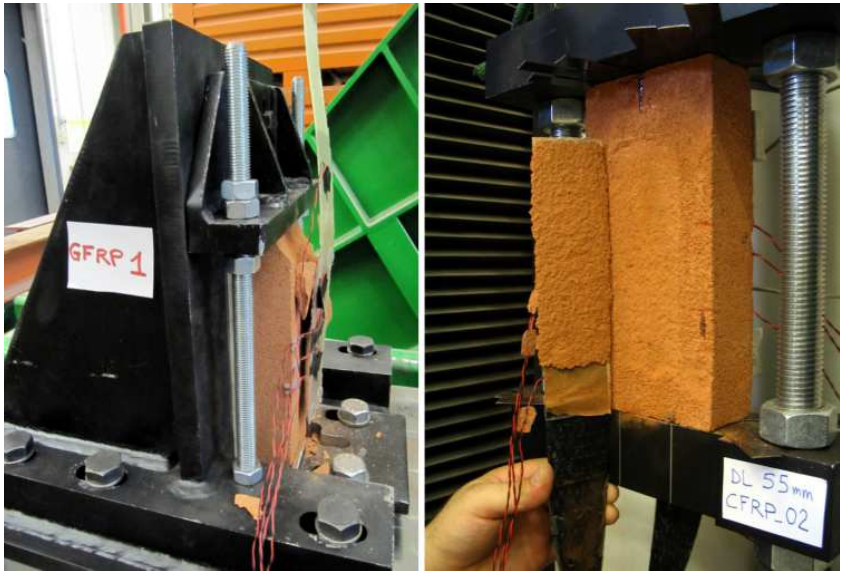
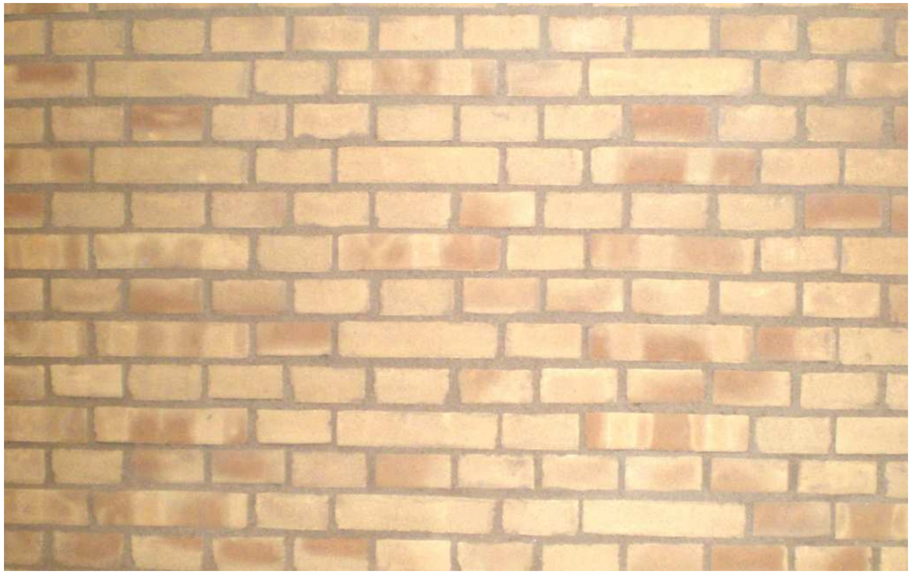
BACKGROUND: FRP-TO-MASONRY BOND BEHAVIOUR

- The application of Externally Bonded Fibre-Reinforced Polymers (EB FRP) represents a valid option to strengthen existing masonry buildings, also in the case of historical structures where special requirements need to be met.
- The FRP-to-masonry bond behaviour is a crucial issue for design and effectiveness of EB FRP applications.
- Differently from concrete substrates, masonry presents a very wide variability in terms of texture and constituent materials, and mortar joints represent geometrical and mechanical discontinuities that can interrupt the effective resisting bonded area.





PLANNING OF SHEAR TESTS

- Within this context, **twenty-two** Single-Lap Shear Tests (SL-ST) were carried out.
- They were aimed at outlining a **methodology** to investigate the adhesion issue of composite materials bonded to brick masonry: the approach (previously adopted by the authors) consists in testing the bond of reinforcements applied to (i) **single clay or stone bricks**, (ii) **blocks made of mortar**, and (iii) **prisms with mortar joints**.

- The experimentation includes five shear tests performed on single **natural limestone** (leccese stone) bricks and five on **lime-based mortar** blocks, and twelve tests carried out on **five-course masonry prisms** made by those materials.
- Unidirectional **glass reinforcements** (GFRP) **50 mm wide** were applied to all the samples.

Specimen	Anchored	$L_b = 200$ mm	$L_b = 195$ mm	$L_b = 130$ mm	$L_b = 65$ mm
Stone block	3	2			
Mortar block	5				
Masonry prism	3		3	3	3

MATERIALS

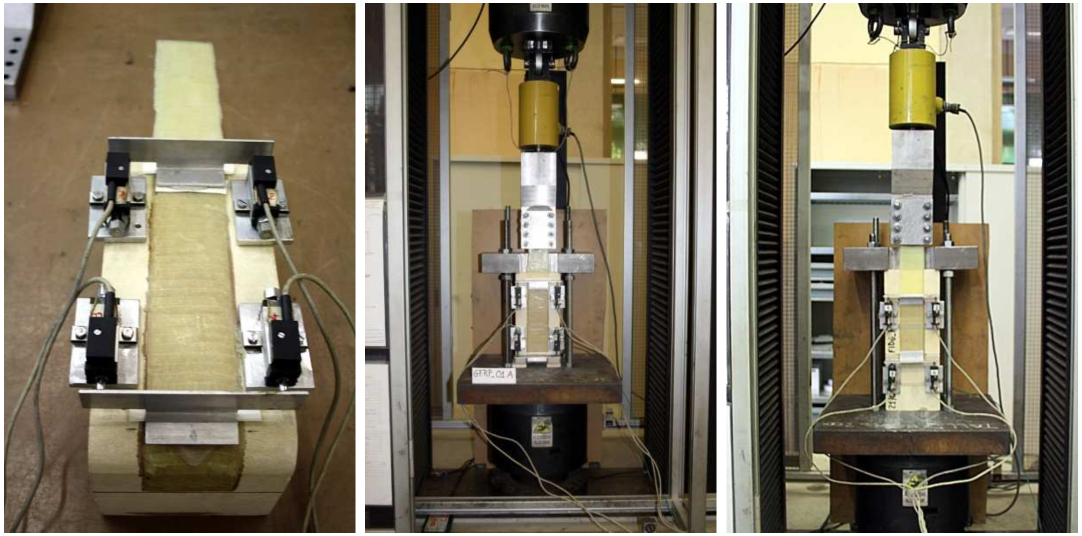
- ❑ Masonry was made of solid calcareous stone blocks (250x120x55mm³) kindly provided by the University of Salento (Lecce, Italy), and lime-based premixed mortar (Tassullo T30V).
- ❑ The epoxy-based glass reinforcement provided by Fidia s.r.l. (FidGlass Unidir 300 HS73) has the following properties:
  - o average tensile strength of 1141 N/mm²;
  - o average strain at maximum load of 1.5%;
  - o average elastic modulus of 80120 N/mm² (30-60% of strength);
  - o equivalent thickness of 0.120 mm (from datasheet).

Material	compressive strength [N/mm²]	flexural strength [N/mm²]	splitting strength [N/mm²]
Leccese stone	20.5 (6%)	2.59 (15%)	2.13 (10%)
Mortar T30V	4.14 (15%)	1.37 (3%)	

SAMPLES AND TEST PROCEDURE

- An unbonded area close to the loaded end (LE) was observed to reduce possible edge effects: it was **30 mm** for single stones and mortar blocks, and **65 mm** (one brick and one mortar joint) for masonry prisms. The bonded area for prisms started in correspondence of the second brick, differently from the previous authors' experience.
- **Test machine**: software-controlled electro-mechanic universal machine, Galdabini SUN60.
- The free end of each reinforcement strip was connected to the test machine with quick-setting **vinylester resin**.
- A 50 kN **load cell** was connected through a ball joint to the top machine head; four **potentiometers** (stroke of ±5 mm) were paired to monitor at LE and UE.

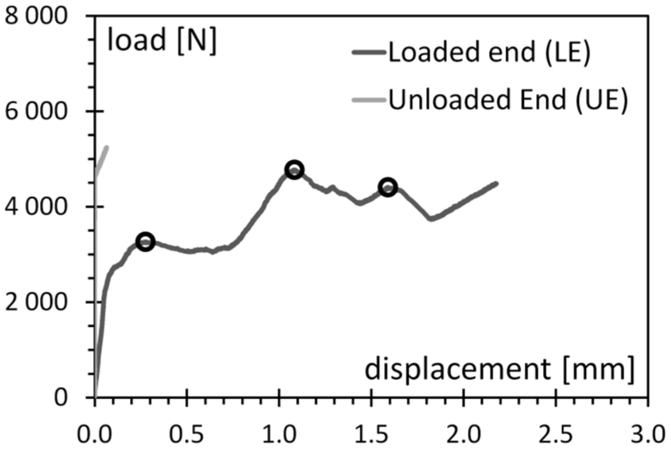
- Tests were performed under **displacement control** with a rate of **0.3 mm/min** for the machine beam.
- The data acquisition rate was **10 Hz**.
- All tests were **monotonic except two cyclic** tests carried out on mortar specimens.



RESULTS

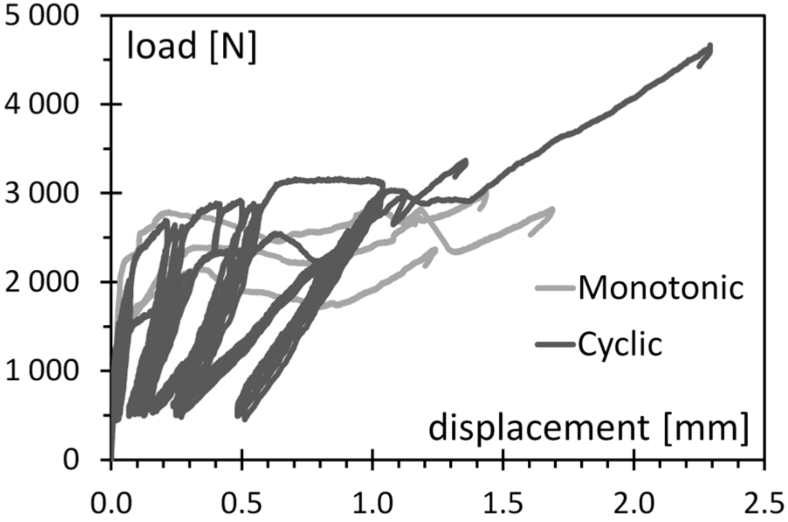
- ❑ In all cases, failure was due to the **loss of adhesion** of the reinforcement, with detachment of a thin layer of stone, or a thicker portion of mortar.
- ❑ For prism specimens with a bonded length **L_b of 65 mm** the failure was abrupt.
- ❑ Prisms with **longer L_b** showed, after a **first peak** load and the detachment from the first brick (sudden load drop and rise of LE displacements), a phase of load increasing until a **second peak** occurred (detachment from the subsequent brick) with another load drop, and **so on** for a third time in case of L_b of 195 mm and end-anchored samples.
- ❑ The first peak (prisms) is never the higher, differently from what observed in prisms made of clay bricks where bond started at the first joint: this supports the idea that the deeper failure surface at a mortar joint causes a sort of **mechanical interlocking** that improves the resistance, while **joints split the bonded area** preventing a full development of strength.

TYPICAL LOAD PROGRESS FOR PRISMS

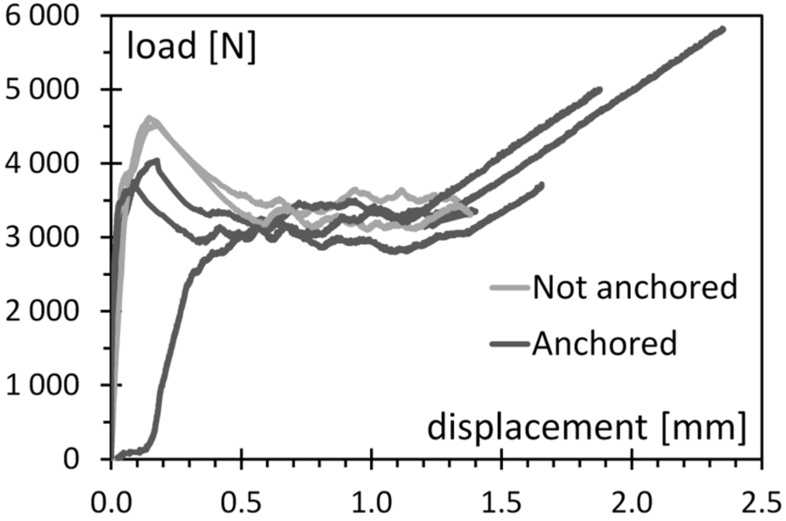


LOAD-DISPLACEMENT CURVES

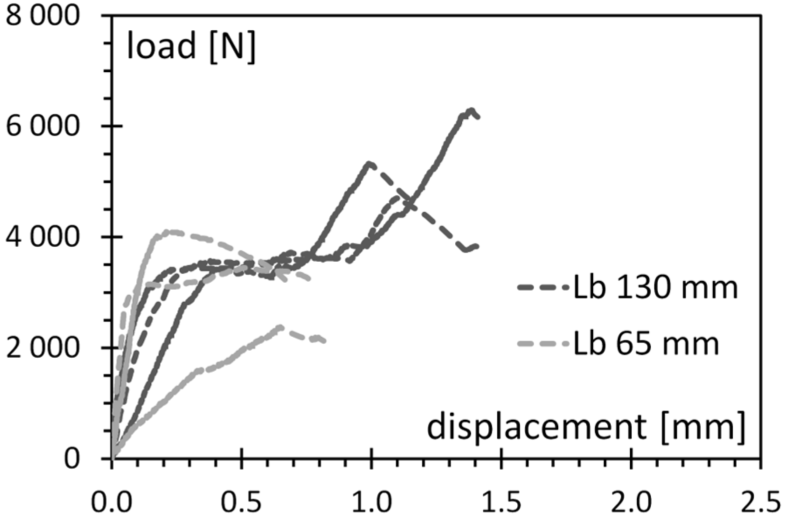
MORTAR

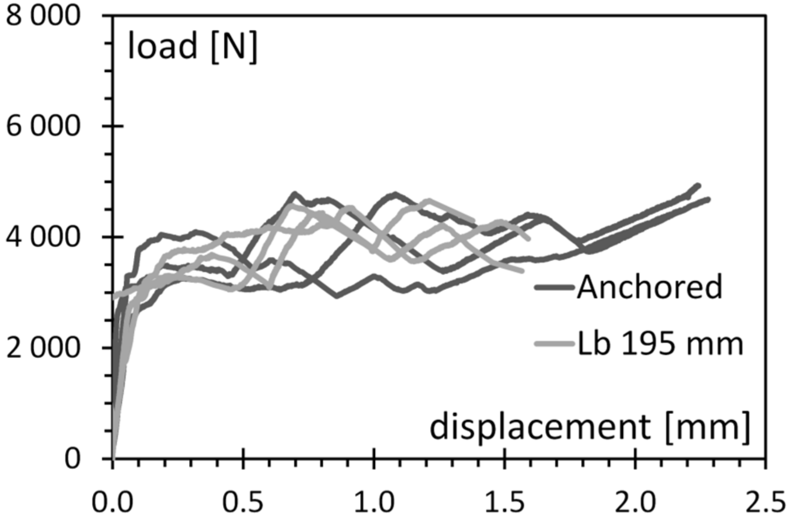


STONES



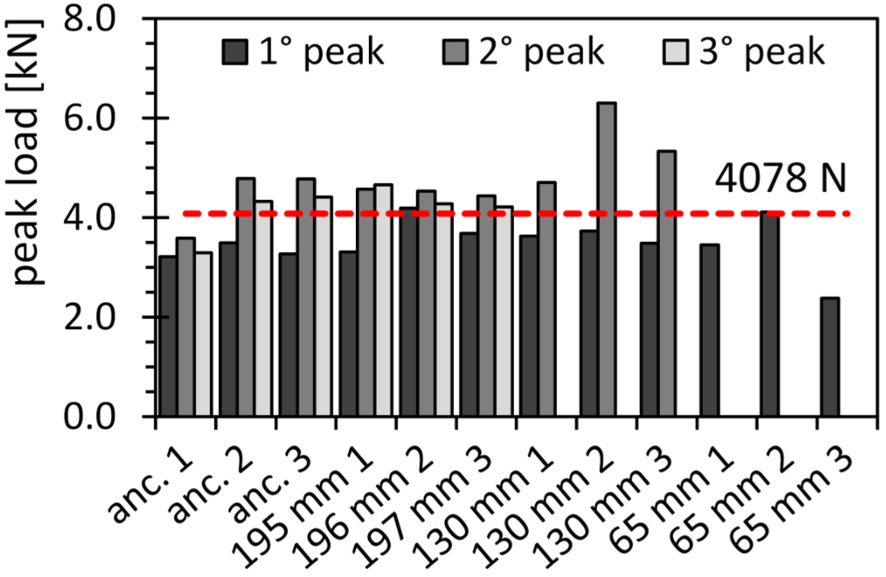
PRISMS



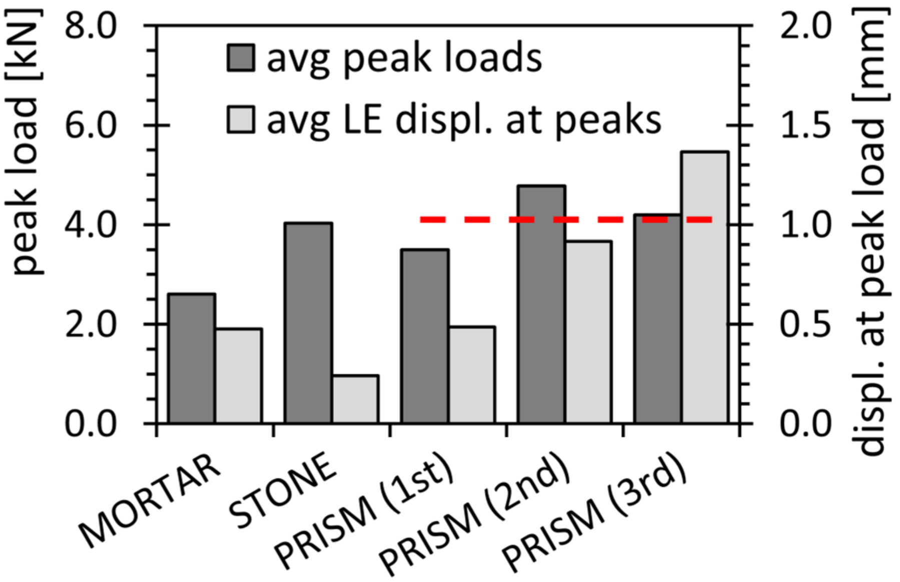


COMPARISON OF PEAK LOADS AND RELATED DISPLACEMENTS

PEAK LOADS OF PRISMS ONLY



AVERAGE RESULTS FOR ALL MATERIALS



SUMMARY (COV IN BRACKETS)

	Mortar	Stone	Prism (1st)	Prism (2nd)	Prism (3rd)	Prism (all)
Peak load [N]	2609 (15%)	4029 (14%)	3494 (13%)	4779 (15%)	4196 (11%)	4078 (19%)
LE displ. at peaks [mm]	0.477 (56%)	0.241 (93%)	0.487 (46%)	0.917 (27%)	1.367 (18%)	--

CONCLUSIONS

- Based on the performed tests (mortar blocks, stone bricks and masonry assemblages with a 50 mm strip of EB GFRP), it was observed that **mortar joints**, consistently with previous experimentations carried out by the authors, for **this combination** of stone units (similar in terms of strength to the formerly adopted clay bricks) and weaker lime mortar (the same product of the earlier tests), had a **strong influence** on the bond behaviour.
- Bonded lengths longer than one stone unit and one mortar joint do not provide higher strength, which was anyway **comparable** to that measured for single stones having nevertheless a uniform bonded area 200 mm long, whereas mortar blocks showed lower strength but deeper failure surfaces.
- Basically, the detachment probably proceeded by joint-brick portions, and the performance of units bonded for only 55 mm appeared to be improved by the formation of a sort of **mortar tooth**, in correspondence to each joint, which gave a mechanical **interlocking**.
- Thus, masonry joints could imply a **double effect** since they **split the bonded area** reducing the strength and somehow preventing the diffusion of tangential stresses, but their deeper ruptures **improve the overall behaviour** by providing an additional resisting mechanism.
- Finally, as expected, the end anchorage of FRP strips allowed for a stable test progress.

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THANK YOU, QUESTIONS?

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