

FABRIC REINFORCED CEMENTITIOUS MATRIX (FRCM) SYSTEMS FOR THE STRENGTHENING OF DIGITAL CONCRETE STRUCTURES

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AIM

3D concrete printing (3DCP) is a new smart technology, recently introduced in the field of civil engineering to fabricate concrete buildings. Thanks to this novel construction approach, structural elements can be built additively, without using formworks, by means of a robotized material casting. Despite this significant advantage, **new materials engineering challenges** are introduced, as concrete is imposed to fulfil all the requirements commonly carried out by the formwork [1] [2]. Furthermore, the concrete admixture needs to be provided with particular rheological and hydration properties for printability [3]. From a structural point of view, one of the main issues related to the digital fabrication with concrete concerns with the reinforcement implementation [4]. Given the hardness, highlighted in the literature, of incorporating the traditional reinforcement made of steel rebars into 3D printed concrete structures (due to the automatic casting processes used in 3DCP which, in most cases, lead to an impossibility of embedding steel reinforcement in the concrete), new strengthening techniques for the reinforcing of these constructions need to be investigated. **Fabric Reinforced Cementitious Matrix (FRCM)** composites, comprised of high strength fabrics (including, **steel**, basalt, glass, PBO and even natural fabrics) **externally bonded** with inorganic and eco-friendly matrices (either lime or cement mortar), could be a proper solution to fulfil this challenging structural task, by also accounting for the environmental sustainability [5]. The efficiency of FRCM systems for the strengthening of 3D printed structures **are experimentally investigated**, starting from the **material scale** (in order to characterize the **bond properties**, i.e. the adhesion of FRCM systems to digital concrete substrates), up to the **structural scale** (by performing tests for the evaluation of the behavior of **3D printed structural elements**, such as beams, wall panels, columns and double-curvature elements, **reinforced with FRCMs**) [5] [6].

3D PRINTING

Powder-based

Powder-based is a method of digital construction that uses a binder jetting 3D printer. In this technique a binder solution is selectively deposited onto the powder bed through a series of small nozzles, bonding these areas together to form the pre-designed solid part one layer at a time. The final object is removed after a specific drying time and excess powders are eliminated by an air jet



Technologies

Extrusion-based

Extrusion-based additive manufacturing of concrete occurs when "printable" cement-based material is extruded through nozzles made of different sizes to form a layered structure



Our choice: Delta WASP 3MT



3D Printer	Type	Material	Country
Construction 3D	Robotic arm	Concrete/Earth materials	France
ICON Vulcan II	Gantry system	Concrete	USA
BOD2	Gantry system	Concrete	Denmark
Delta WASP 3MT	Delta system	Concrete/Earth materials	Italy
Apis Cor	Robotic arm	Concrete	Russia
SC3DP Mobile robot	Robotic arm	Mortar/Geopolymer cement	Singapore
Contour Crafting	Gantry system	Concrete	USA

Major additive manufacturing technologies for construction in the industrial and academic contexts.

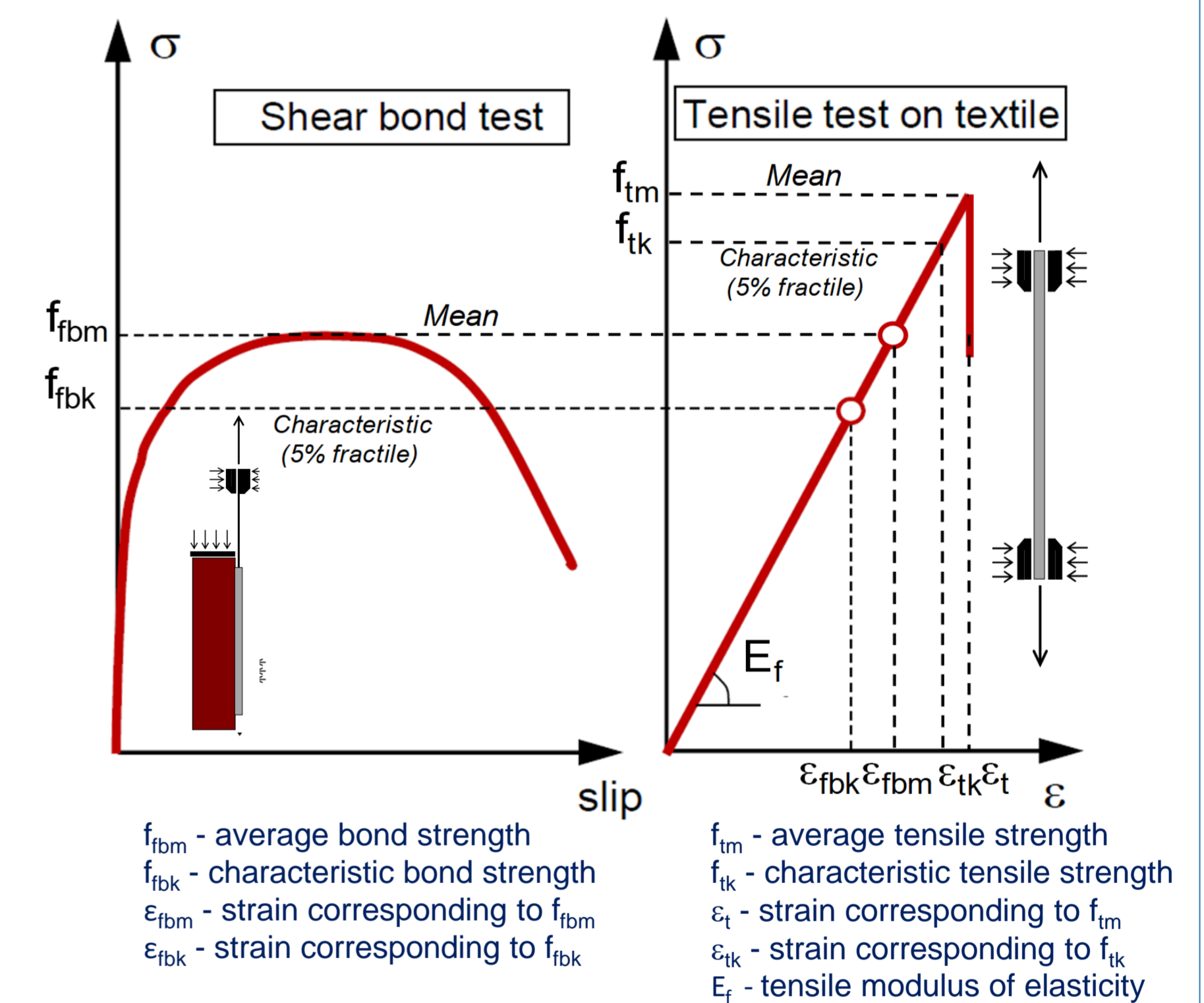
Specimens

- Concrete substrate → GLV steel fabric + Cement based mortar;
- Brick-masonry substrate → GLV steel fabric + Lime mortar; INOX steel fabric + Lime mortar;
- Tuff-masonry substrate → GLV steel fabric + Lime mortar; INOX steel fabric + Lime mortar;
- Stone-masonry substrate → GLV steel fabric + Lime mortar; INOX steel fabric + Lime mortar;



Specimen preparation with concrete substrate and reinforcement system made of GLV steel fabrics and cementitious mortar

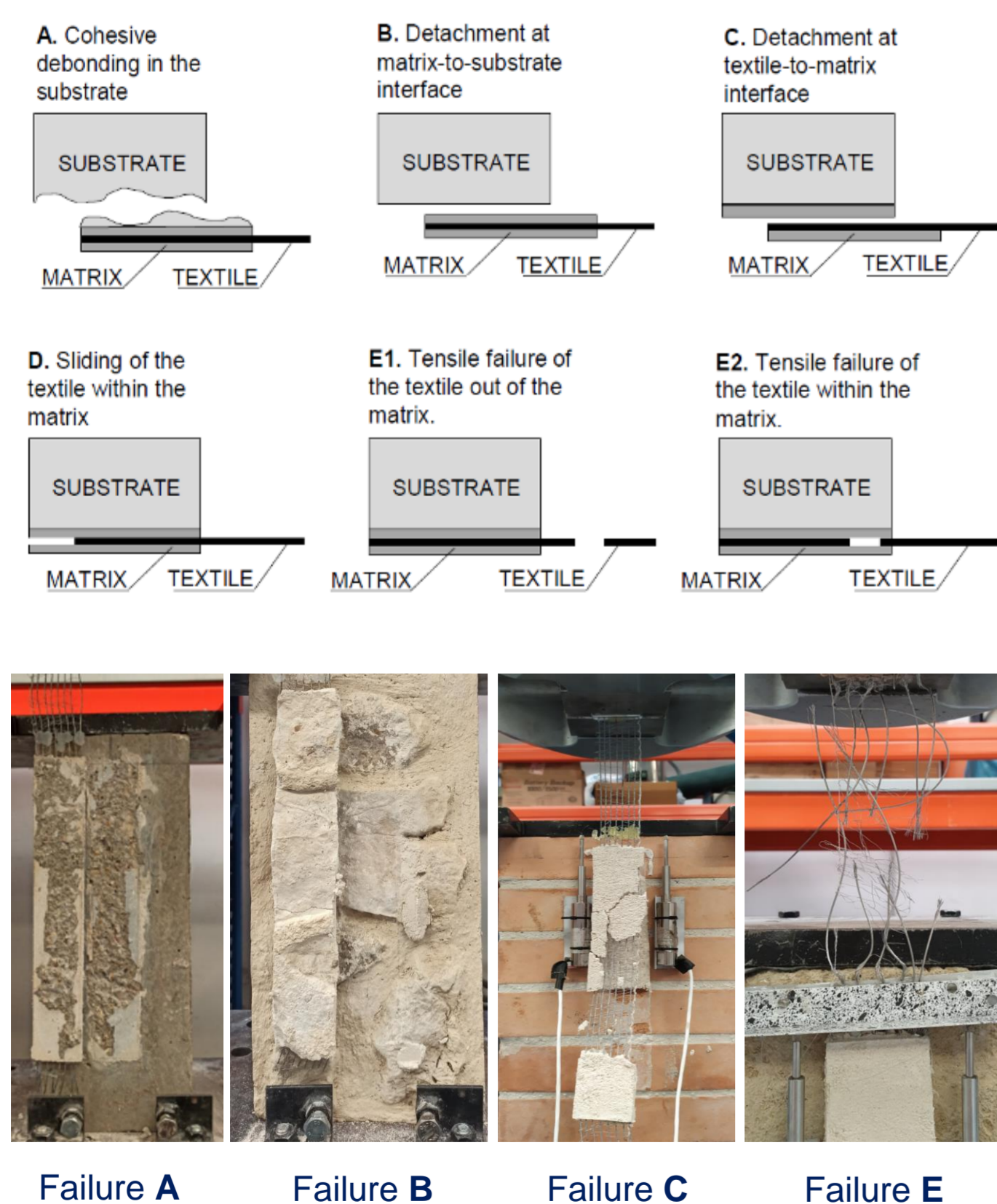
Behaviour



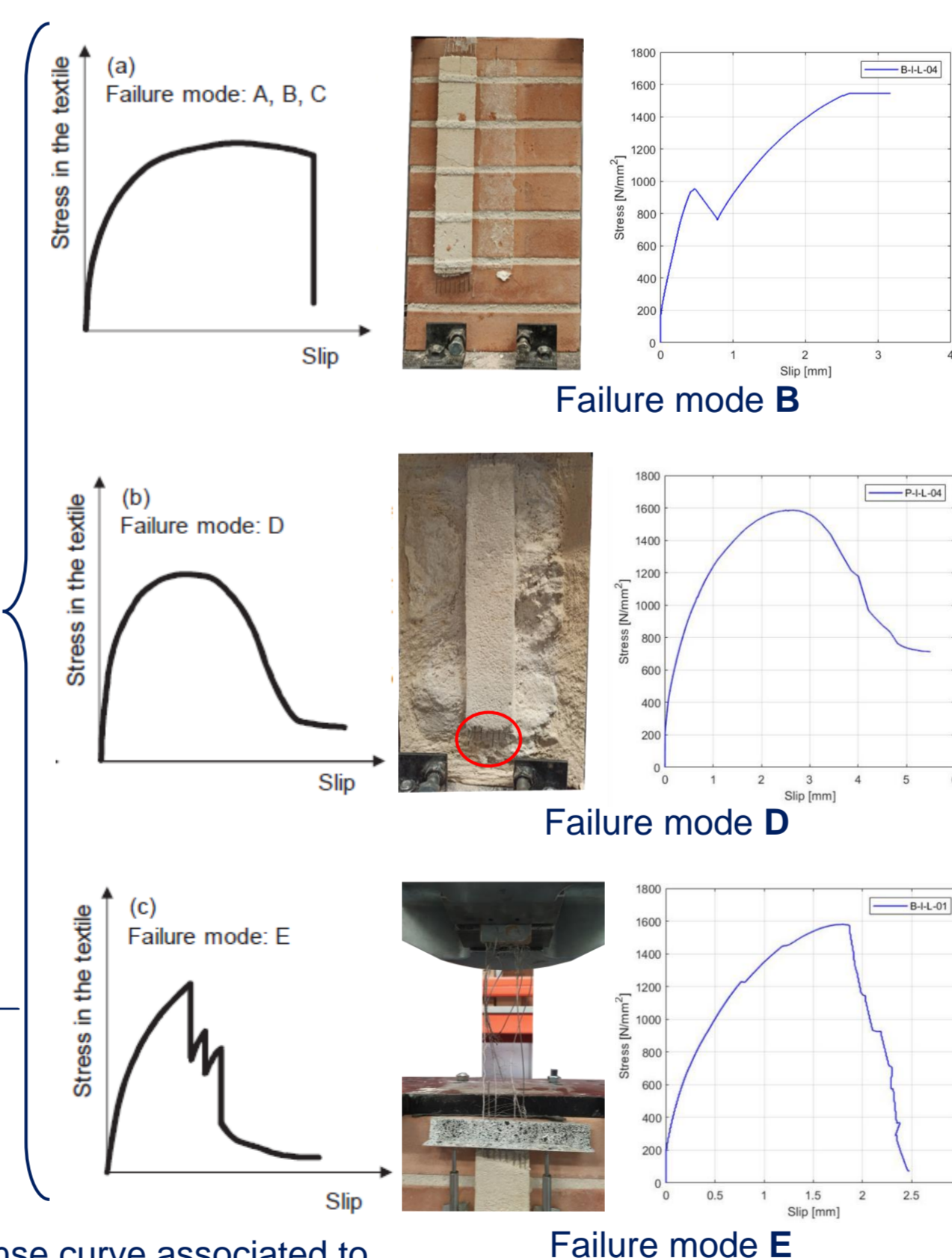
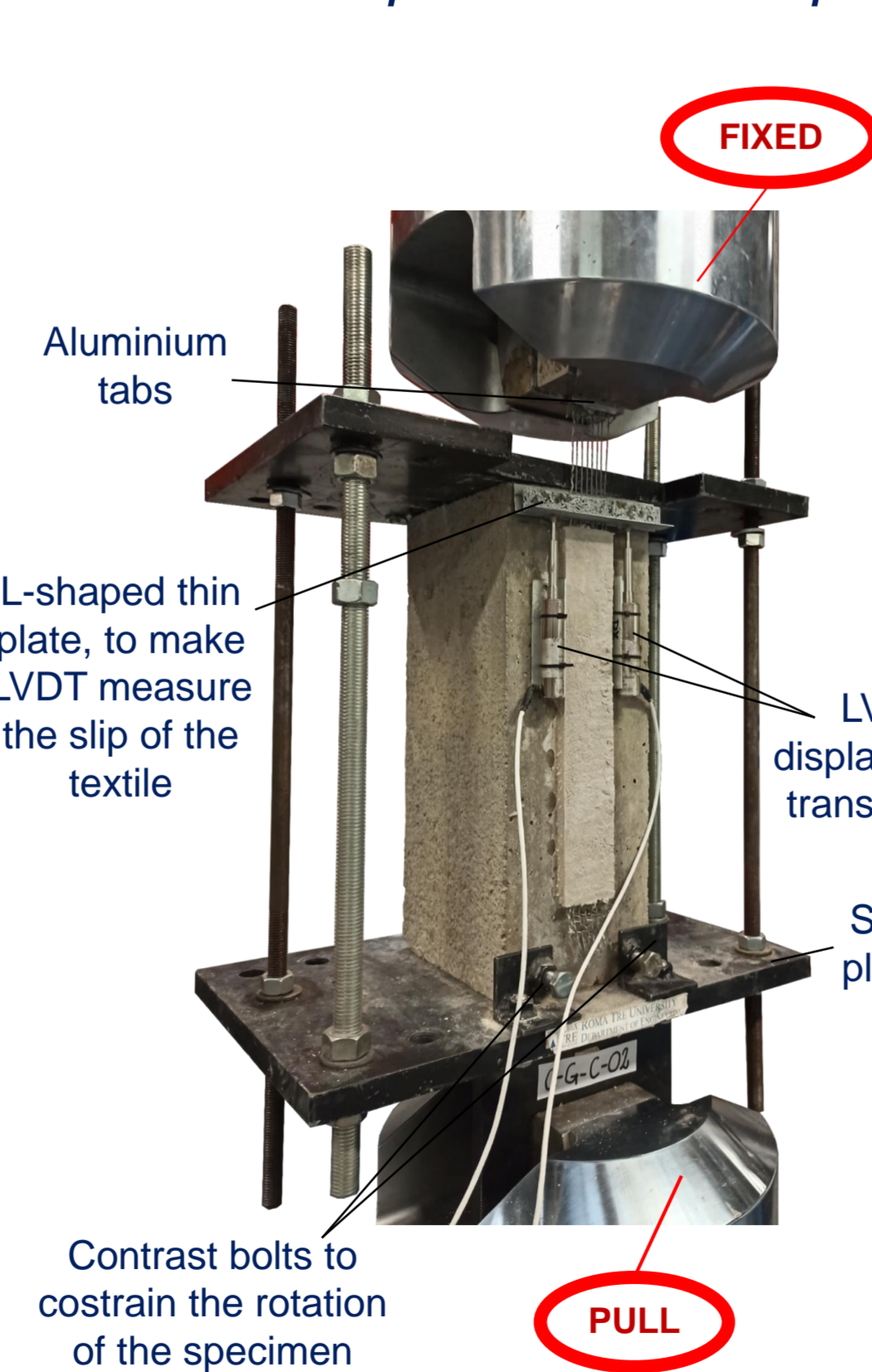
SRG BOND TESTS

Evaluation of Bond strength

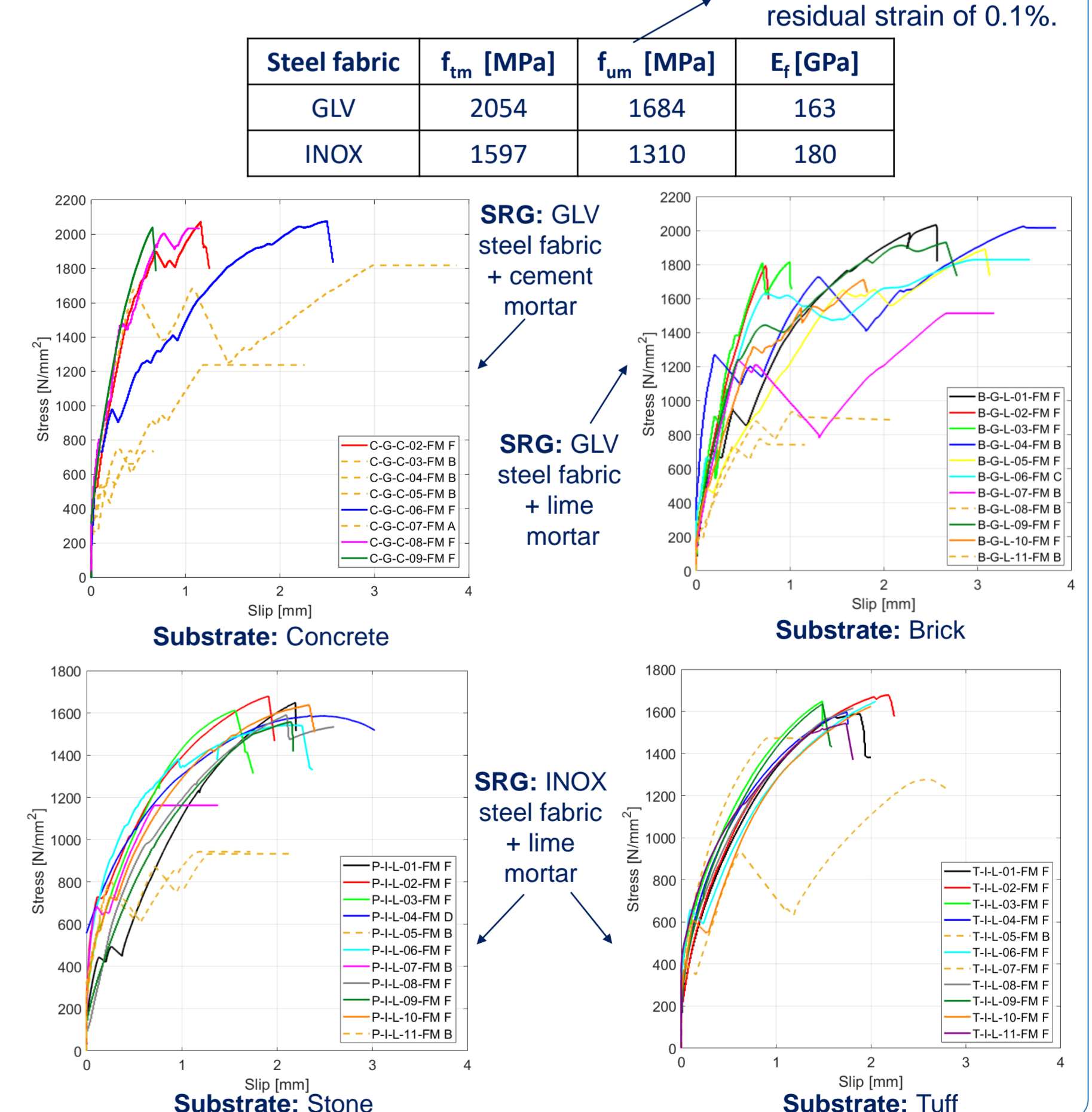
Failure modes



Experimental setup



Experimental results



Publications and works

- Gobbin F., **Fugger R.**, de Felice G. 2019. Modellazione agli elementi distinti per lo studio di interazione della facciata con la parete laterale di alcune chiese nel territorio Aquilano. Atti 18° Convegno Nazionale ANIDIS: L'ingegneria Sismica in Italia, Ascoli Piceno.
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- [1] Menna C., et al. 2020, "Opportunities and challenges for structural engineering of digitally fabricated concrete", Cement and Concrete Research, V. 133.
- [2] Reiter L., et al. 2018, "The Role of early age structural build-up in digital fabrication with concrete", Cement and Concrete Research, V. 112, pp. 86-95
- [3] Marchon D., et al. 2018, "Hydration and rheology control of concrete for digital fabrication: Potential admixtures and cement chemistry", Cement and Concrete Research, V. 112, pp. 96-110.
- [4] Asprone D., et al. 2018, "Rethinking reinforcement for digital fabrication with concrete", Cement and Concrete Research, V. 112, pp. 111-121
- [5] de Felice G. et al., 2014, "Mortar-based systems for externally bonded strengthening of masonry", V. 47, pp. 2021-2037.
- [6] De Santis S., et al., 2017, "Round Robin Test on tensile and bond behaviour of Steel Reinforced", V. 127, pp. 100-120.