



CONSIGLIO NAZIONALE
DEGLI INGEGNERI

Con il supporto scientifico di:



CONVEGNO ON LINE

LUNEDÌ 28 SETTEMBRE 2026, ORE 15.00 - 17.00

**Tecniche di intervento con malte storiche
per la salvaguardia del patrimonio in aree
di crisi e materiali compositi FRCM**

Focus per gli specialisti di ingegneria sulle soluzioni
sostenibili per il consolidamento delle murature storiche

Innovazione FRCM e Soluzioni Green: Sviluppi e applicazioni dei sistemi compositi FRCM con tessuti a base di fibre vegetali

Marco Pepe

*Dipartimento di Ingegneria Civile
Università degli Studi di Salerno*



Overview

- ❑ Introduction
- ❑ FRCM system optimisation
- ❑ Structural scale applications
- ❑ Conclusion and future development

Overview

- ☒ Introduction
- ☐ FRCM system optimisation
- ☐ Structural scale applications
- ☐ Conclusion and future development

Introduction

The use of natural (plant) fibers in TRM systems: advantages



Hemp



Jute



Flax



Kenaf



Lower enviromental impact



Lower economic impact for the production



Easier installation technique



Comparable mechanical characteristic



More affordable material for poor countries

Introduction

The use of natural (plant) fibers in TRM systems: open issue and research objective



Hemp



Jute



Flax



Kenaf

Open issues:

- **Heterogeneity** of natural fibers;
- Water **absorption** capacity;
- **Durability** and long-term performances.

Research objective:

- Optimization of **FRCM** system;
- Application of a **sustainable coating with PLA**;
- Evaluating the possible application at **structural** level.

Introduction

The use of natural (plant) fibers in TRM systems: open issue and research objective



materials



Article

Experimental Characterisation of Lime-Based Textile-Reinforced Mortar Systems Made of Either Jute or Flax Fabrics

Marco Pepe ^{1,2} , Rosario Lombardi ¹, Giuseppe Ferrara ³ , Stefano Agnetti ⁴  and Enzo Martinelli ^{1,*} 

¹ DICiv—Department of Civil Engineering, University of Salerno, Via Giovanni Paolo II, 132, 84084 Fisciano, Italy; mapepe@unisa.it (M.P.); lombarosar@gmail.com (R.L.)

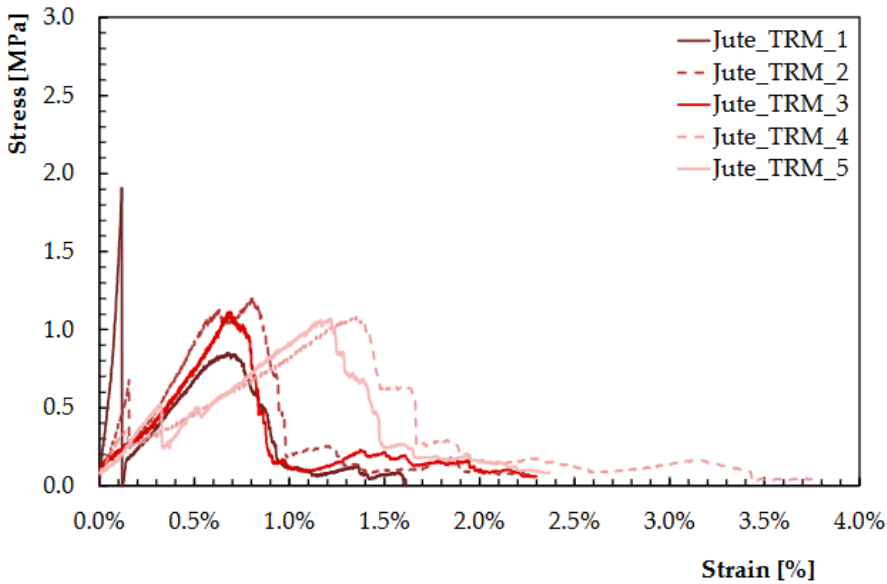
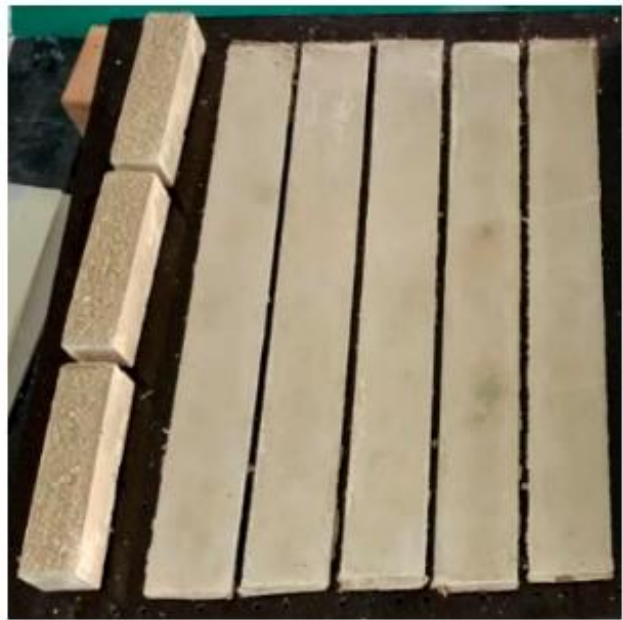
² TESIS srl, Via Giovanni Paolo II, 132, 84084 Fisciano, Italy

³ DISAT—Department of Applied Science and Technology, Politecnico di Torino, Corso Duca Degli Abruzzi, 24, 10129 Torino, Italy; giuseppe.ferrara@polito.it

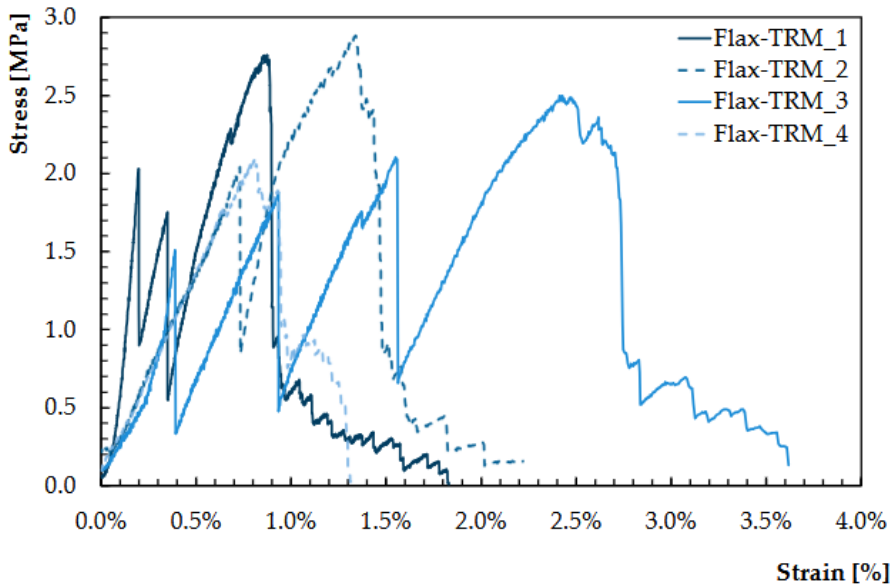
⁴ Kimia s.p.a., Via del Rame, 73, 06134 Perugia, Italy; stefano.agnetti@kimia.it

Introduction

The use of natural (plant) fibers in TRM systems: open issue and research objective



(a)



(b)

Figure 16. Stress–strain curves of Jute-TRM (a) and Flax-TRM (b).

Overview

☐ Introduction

☒ **FRCM system optimisation**

☐ Structural scale applications

☐ Conclusion and future development

Natural FRCM systems

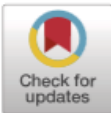
Reinforcement ratio optimisation



Contents lists available at [ScienceDirect](#)

Progress in Engineering Science

journal homepage: www.sciencedirect.com/journal/progress-in-engineering-science



Experimental analysis on the tensile response and cracking process in jute/ flax lime-based textile-reinforced mortars

Marco Pepe, PhD ^{a,b} , Eduardo Sellitto ^a, Bruno Paolillo ^a, Rosario Lombardi ^a,
Giuseppe Ferrara, PhD ^c, Stefano Agnetti, PhD ^d , Flavio Stochino, PhD ^e ,
Enzo Martinelli, PhD ^{a,*}

^a Department of Civil Engineering, University of Salerno, via Giovanni Paolo II 132, Fisciano, SA 84084, Italy

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^d Kimia SpA, Via del Rame 73, Perugia, PG 06134, Italy

^e Department of Civil, Environmental Engineering and Architecture, University of Cagliari, Via Marengo 2, Cagliari, CA 09123, Italy

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Natural FRCM systems

Reinforcement ratio optimisation

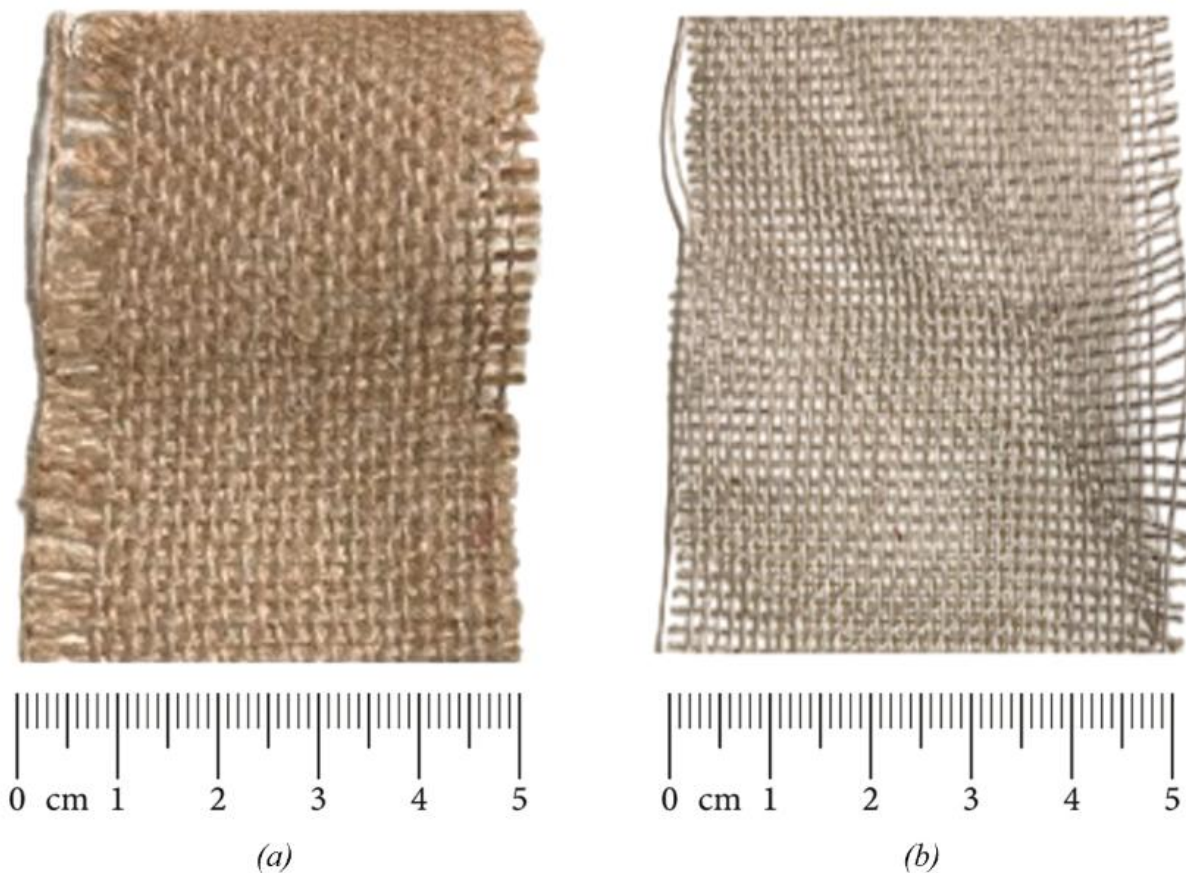


Fig. 1. Representative samples of (a)Jute and (b) Flax textile.



Fig. 3. Representative tensile test on natural textile: Jute.

Natural FRCM systems

Reinforcement ratio optimisation

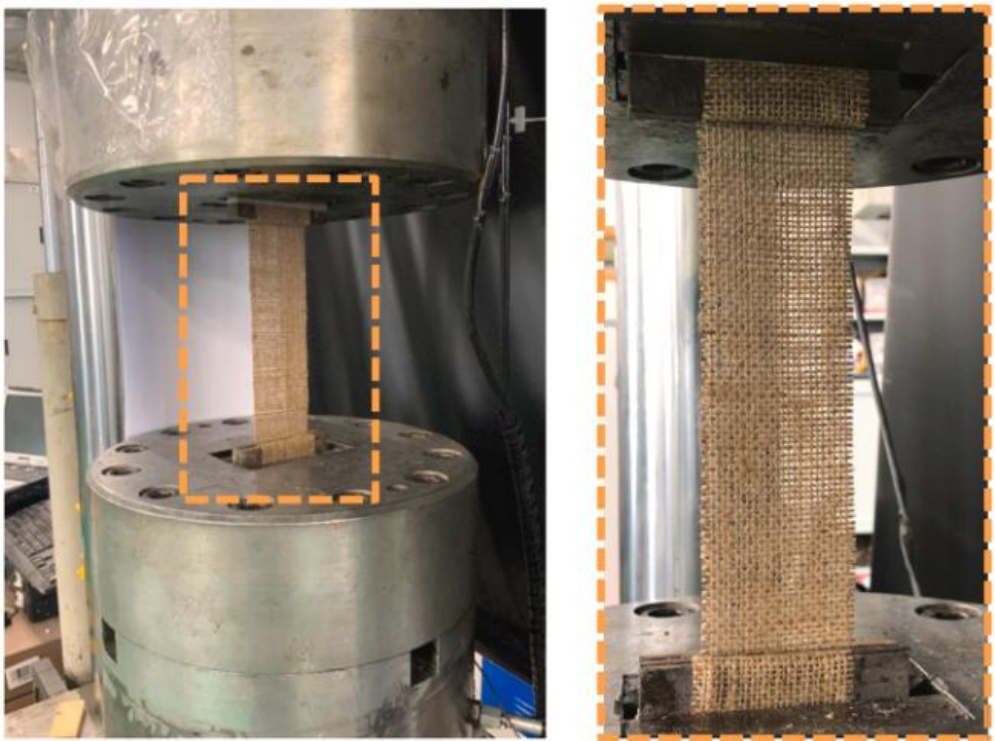
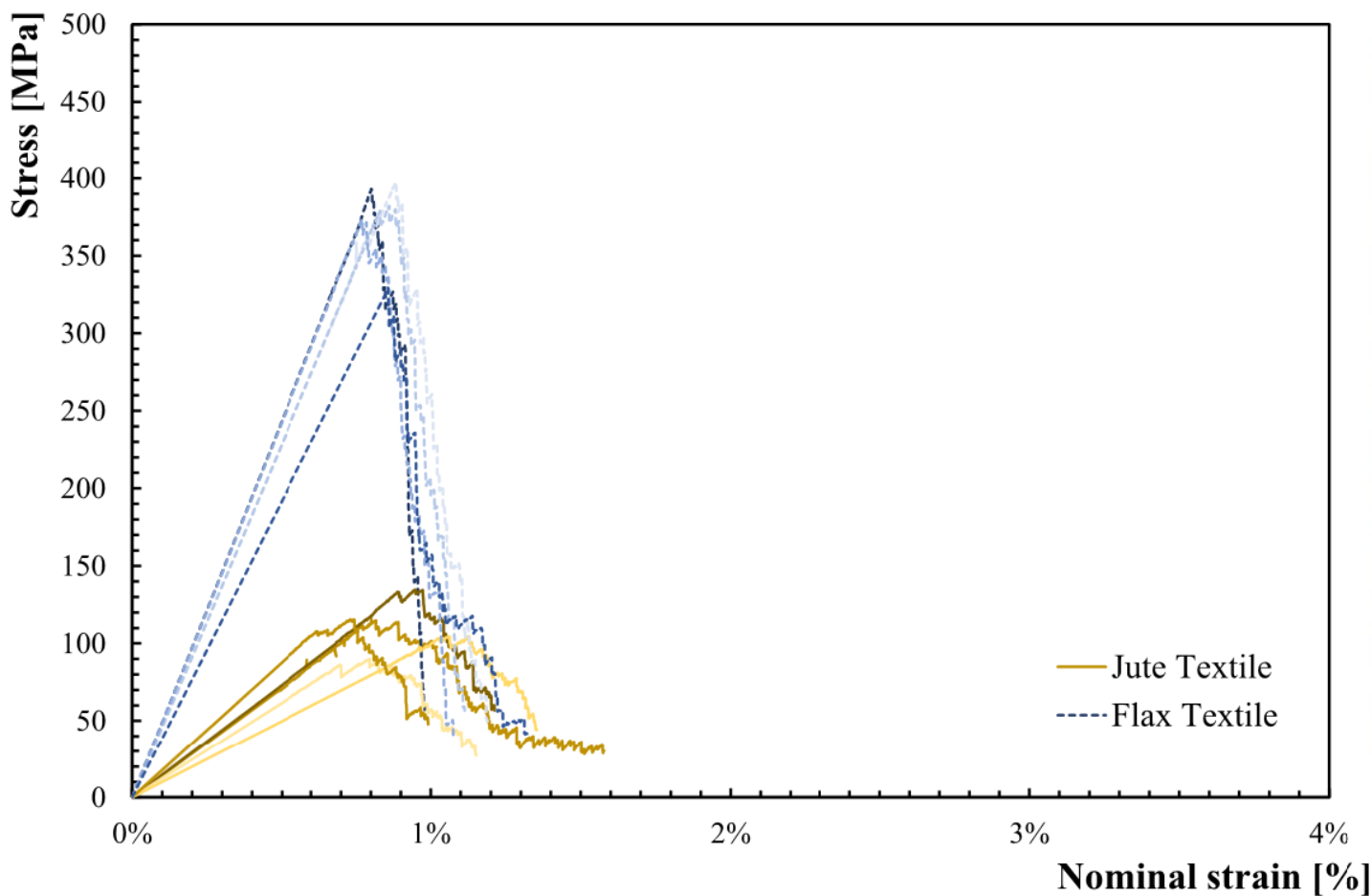
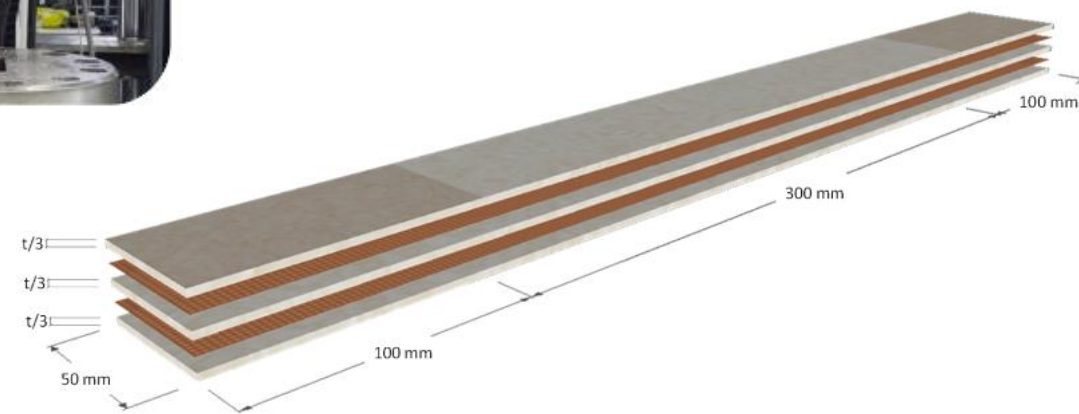


Fig. 3. Representative tensile test on natural textile: Jute.

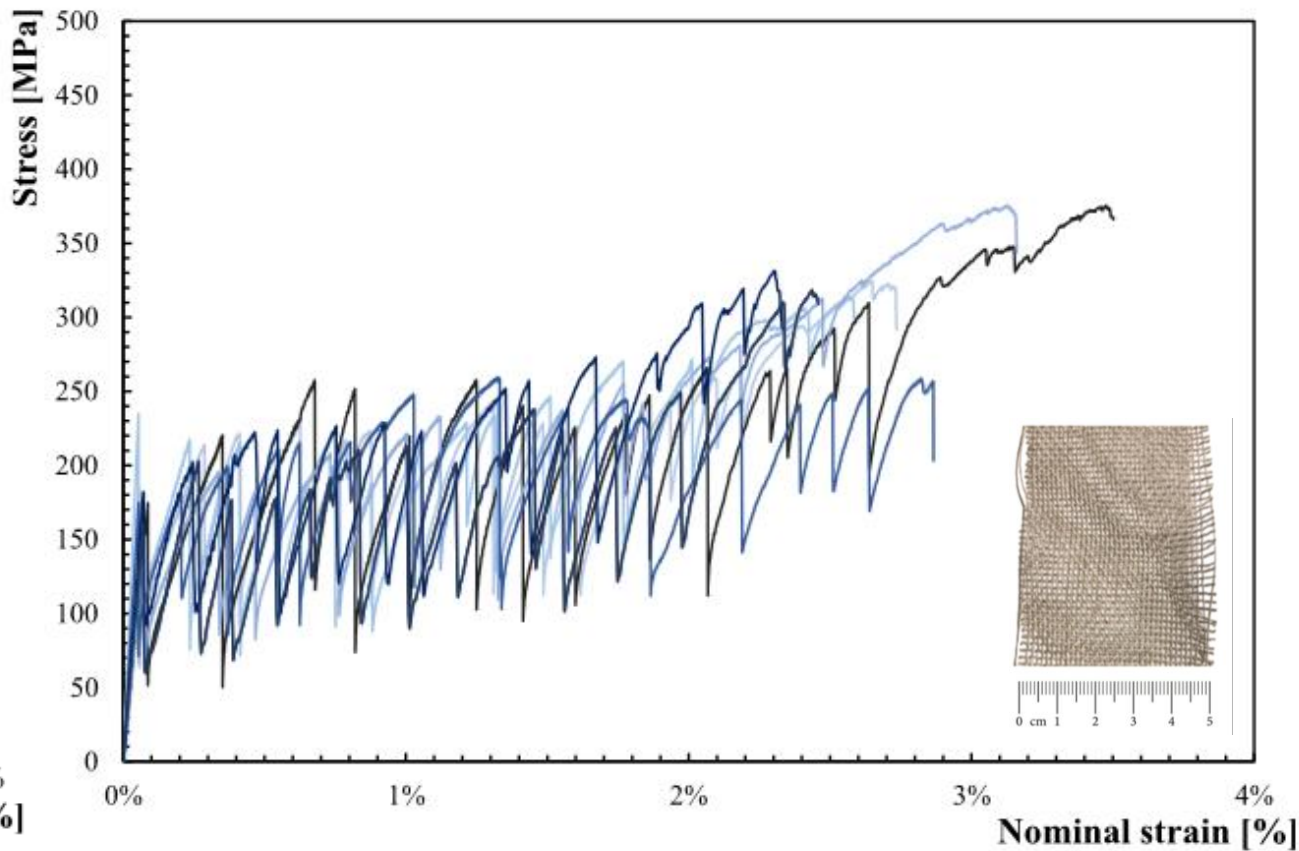
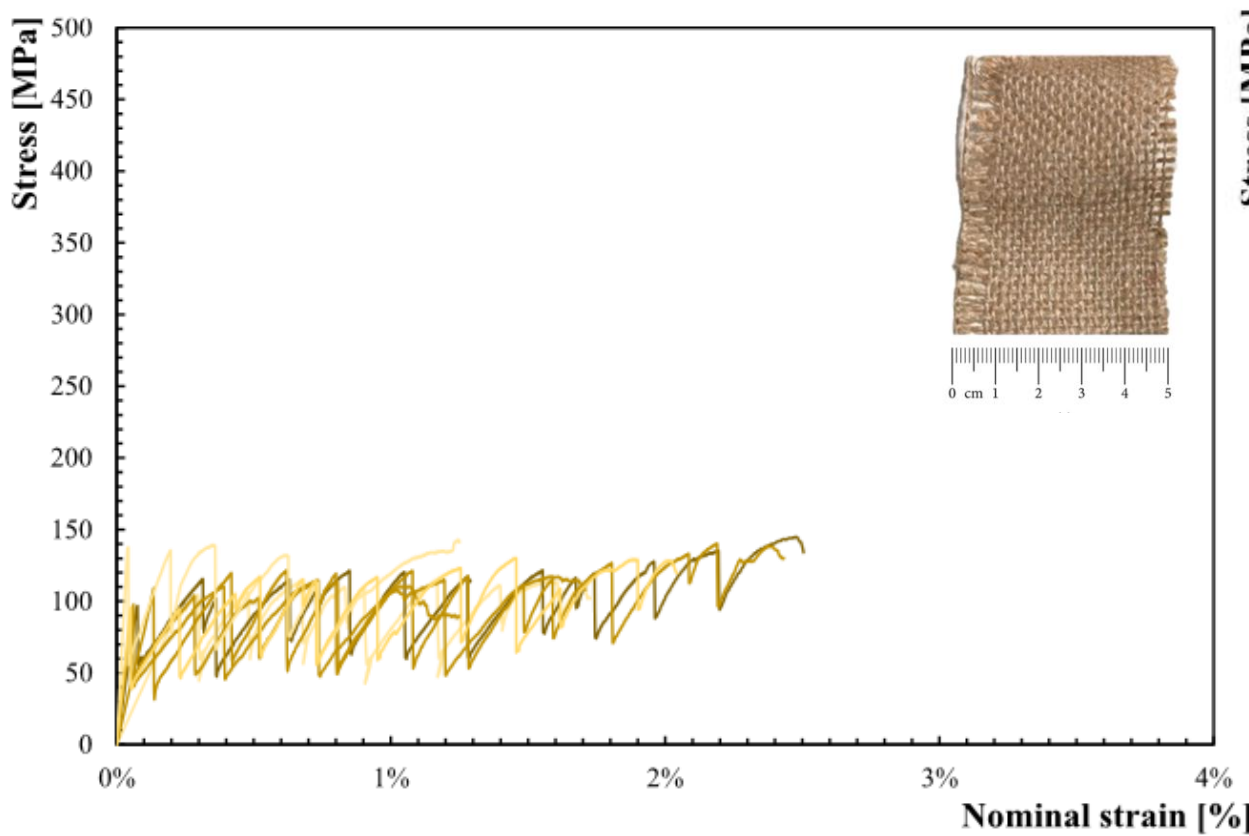
Natural FRCCM systems

Reinforcement ratio optimisation



Natural FRCM systems

Reinforcement ratio optimisation



Natural FRCM systems

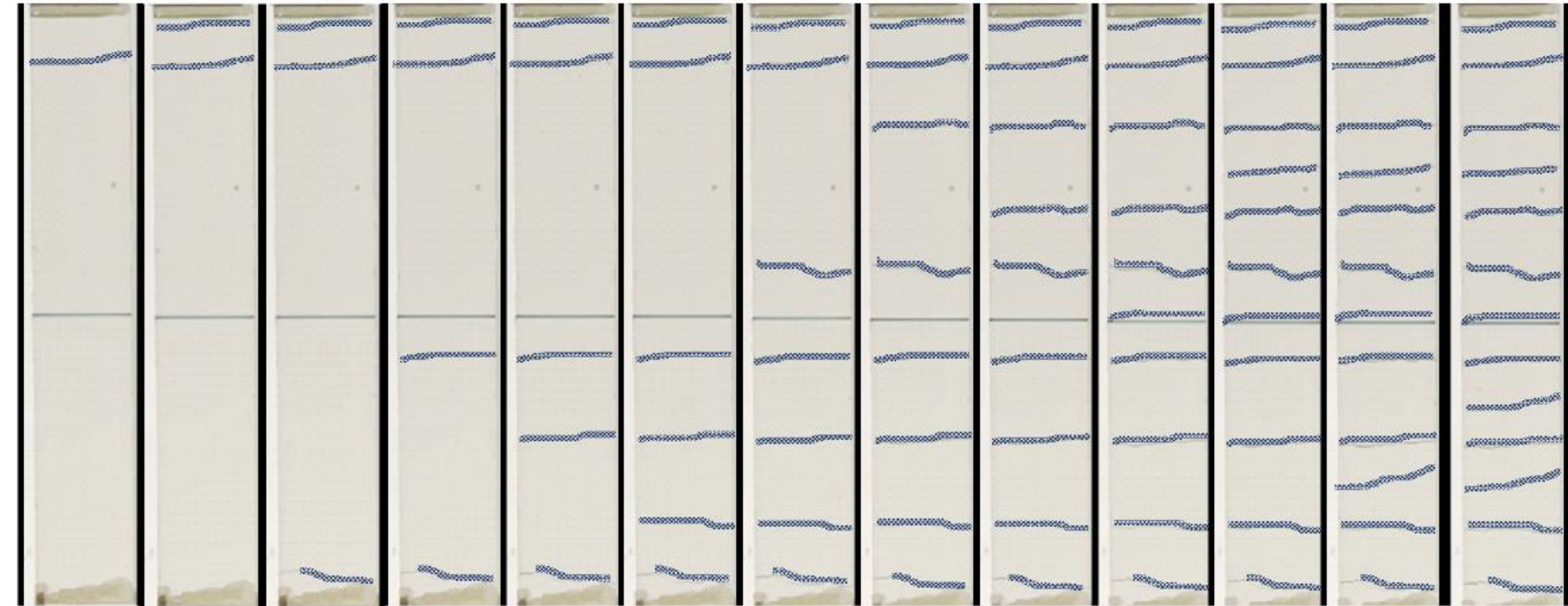
Reinforcement ratio optimisation

Mechanical response of Jute-TRM and Flax-TRM composites.

Parameter	Jute-TMR	Flax-TRM
Average textile stress at maximum load - $\sigma_{\text{max,TRM}}$ [MPa] (range of variation)	121.39 (113.51–126.32)	295.18 (249.08–374.21)
Exploitation ratio [%] (range of variation)	95 (72–136)	61 (60–62)
Minimum number of cracks - $n_{\text{crack, min}}$	6	10
Maximum number of cracks - $n_{\text{crack, max}}$	13	16
Average crack spacing at final stage [mm] (range of variation)	52.23 (33.33–80.00)	27.75 (25.00 – 36.36)

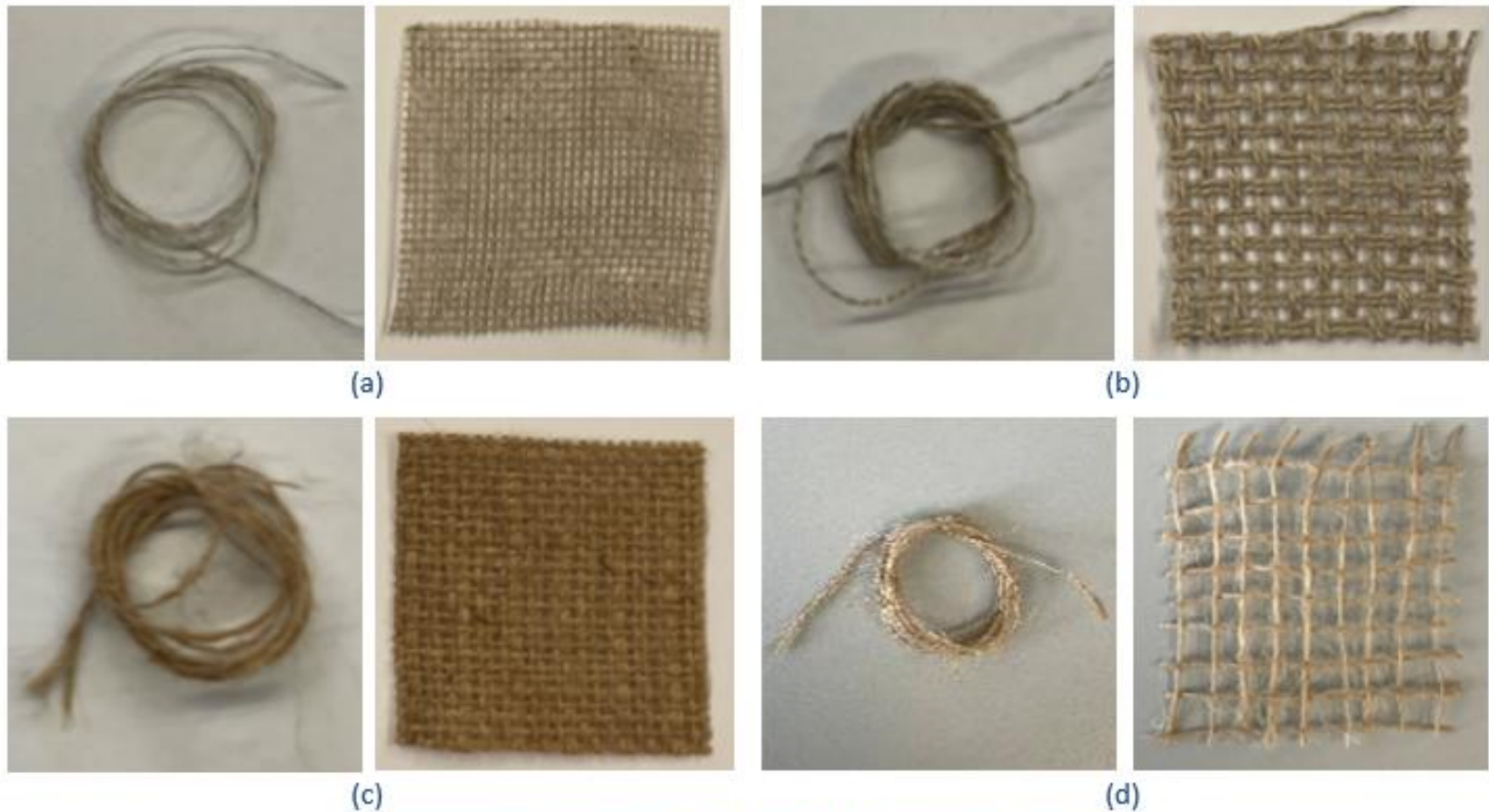
Natural FRCC systems

Reinforcement ratio optimisation



PLA coating optimisation

Coating application



Representative samples of flax and jute yarns/textiles:
(a) Flax-98g/km (b) Flax-302g/km (c) Jute-268g/km and (d) Jute-250 g/km.

Coating

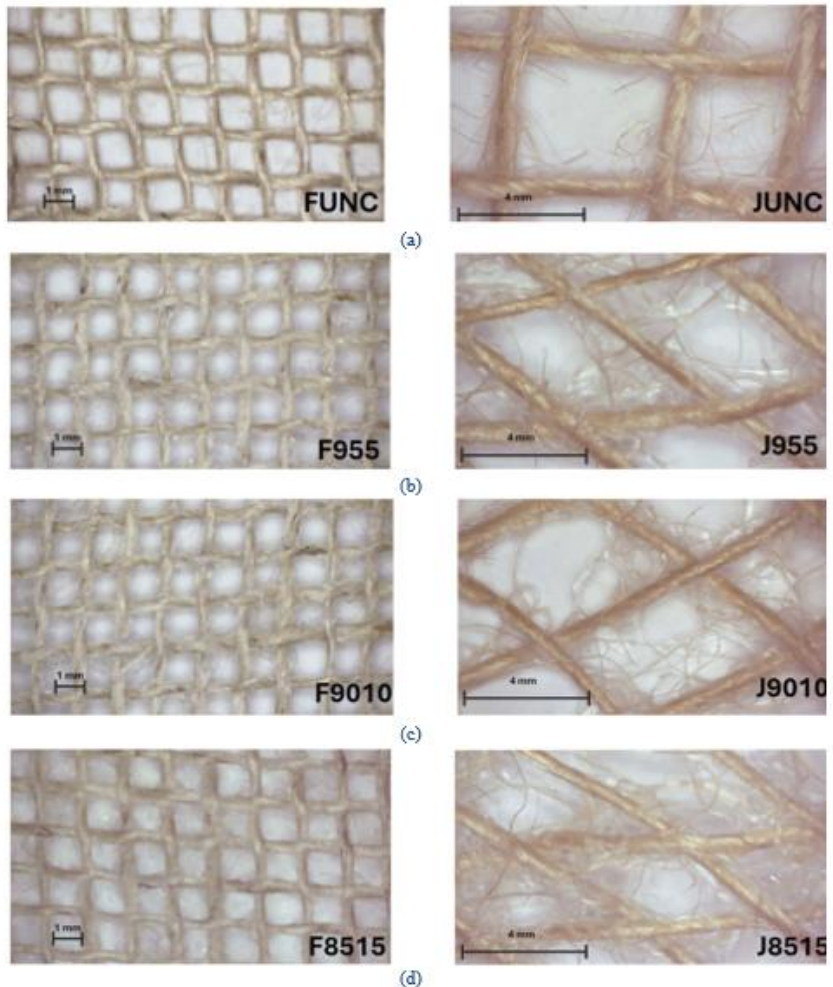
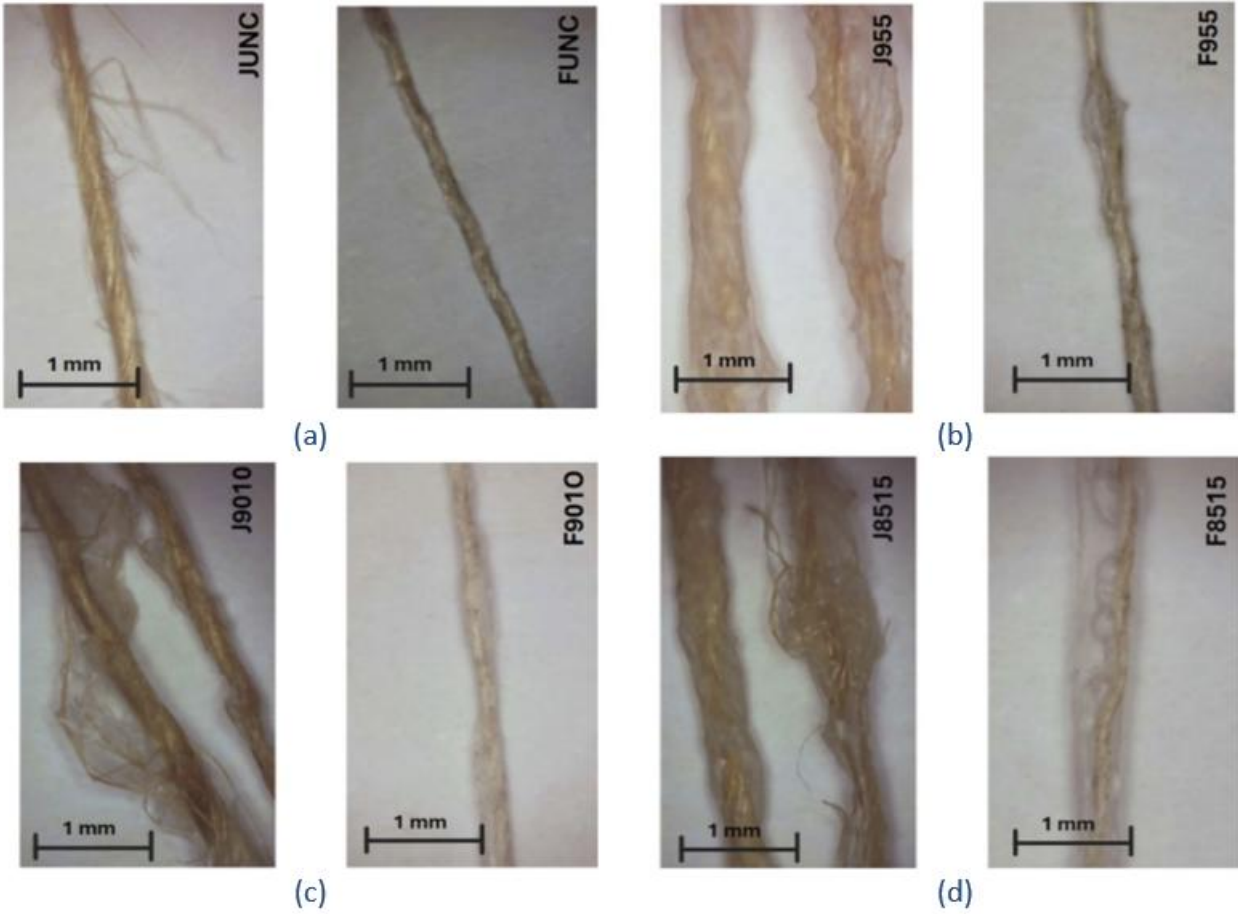
PLA 5% & acetone 95%
PLA 10% & acetone 90%
PLA 15% & acetone 85%



Label	TEX [g/km]	Density [g/m ²]	Mesh density [yarn/cm]
Flax-98g/km	98	125	6.2
Flax-302g/km	302	265	4.4
Jute-268g/km	268	320	5.6
Jute-250 g/km	250	90	1.8

PLA coating optimisation

Yarns microscope images

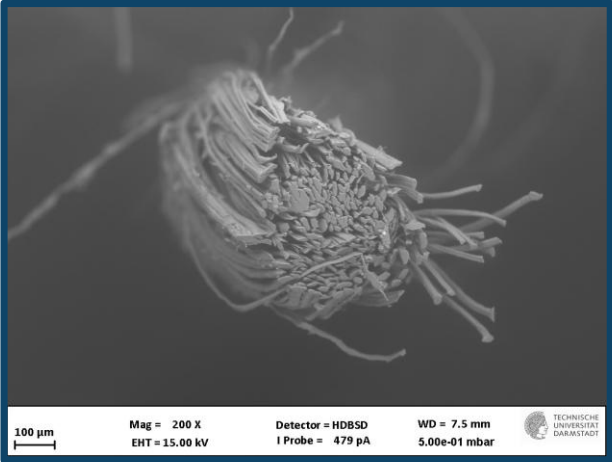


Yarns microscope images

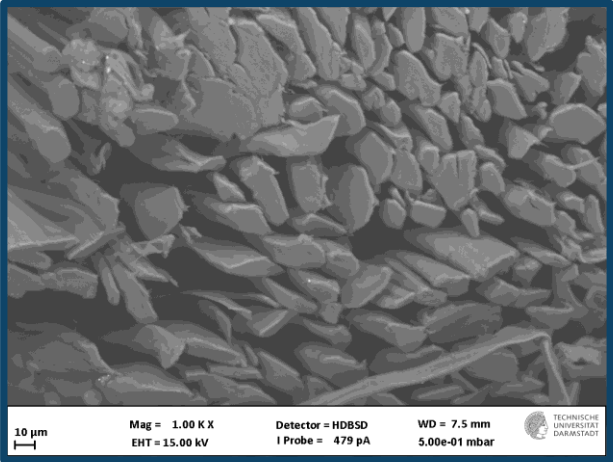
(a) non-impregnated/uncoated flax and jute yarns and (b,c,d) impregnated/coated flax and jute yarns

PLA coating optimisation

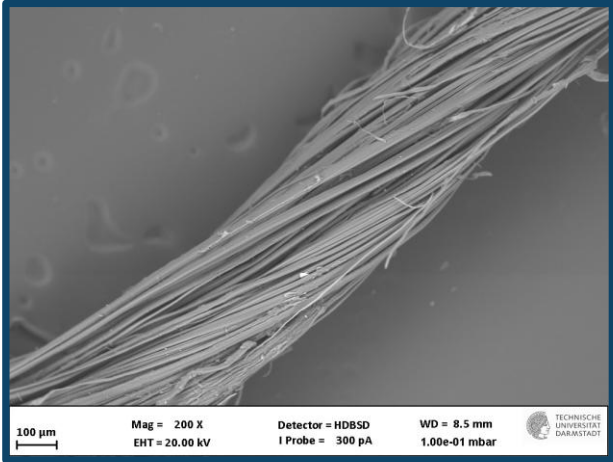
Representative SEM analysis of jute/flax yarns



Cross section of flax yarn

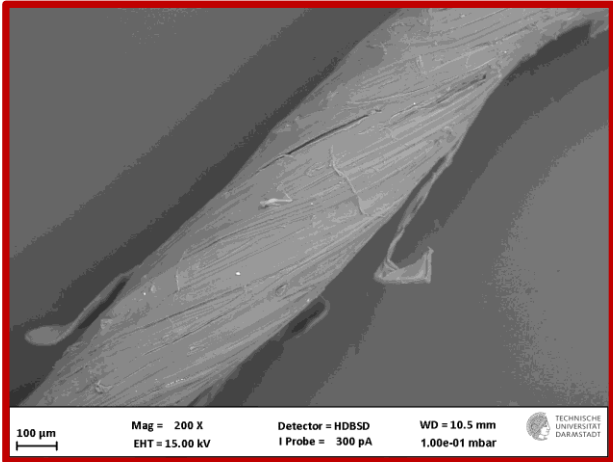
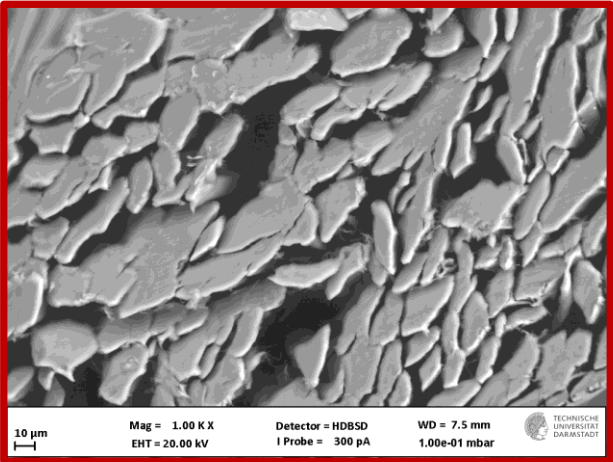
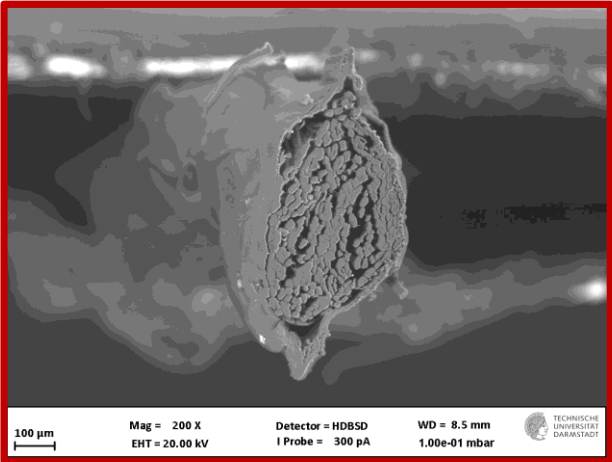


Detail of cross section area



Lateral surface of flax yarn

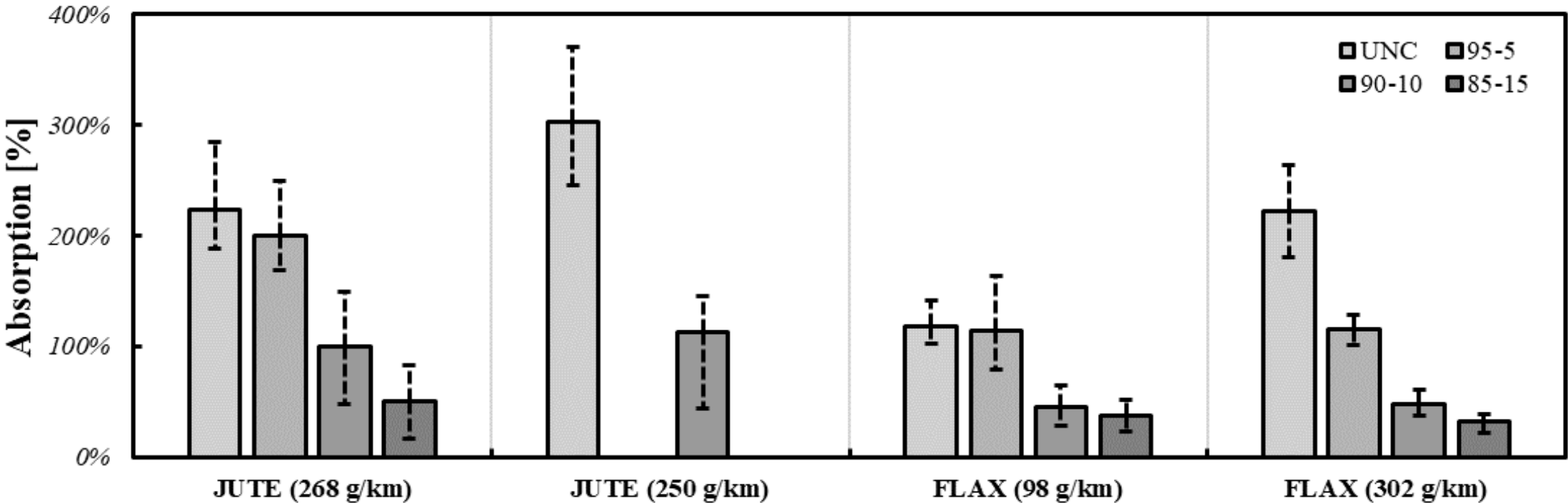
uncoated



coated

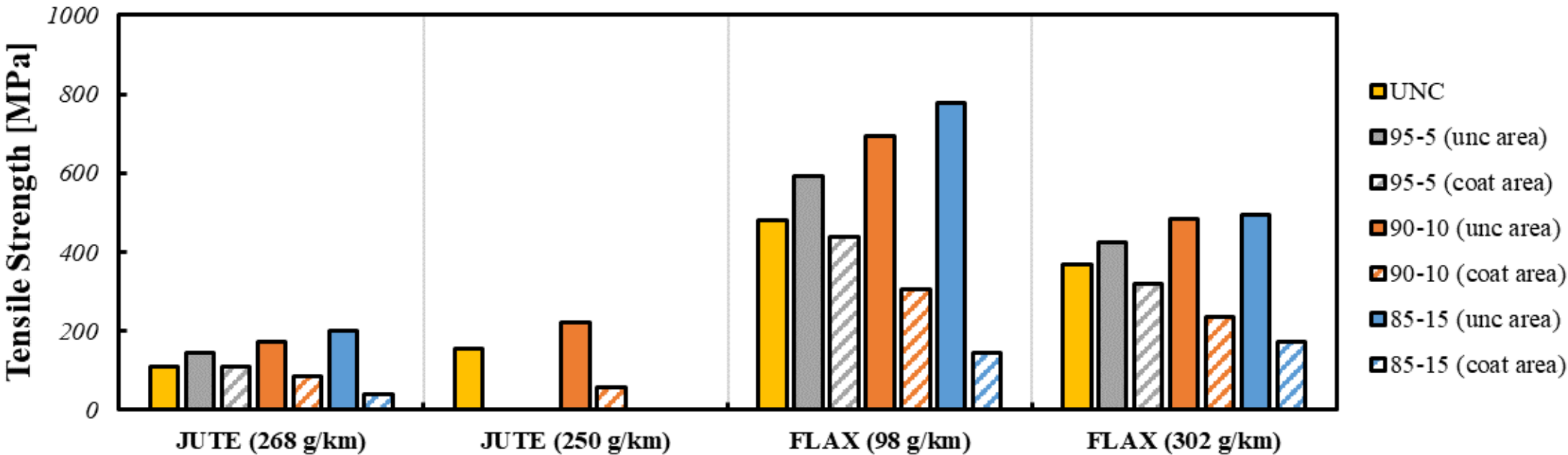
PLA coating optimisation

Influence of coating application on the resulting **water absorption capacity**



PLA coating optimisation

Influence of coating application on the resulting **Tensile Strength**



PLA coating optimisation

FRCC specimen and tensile test protocol

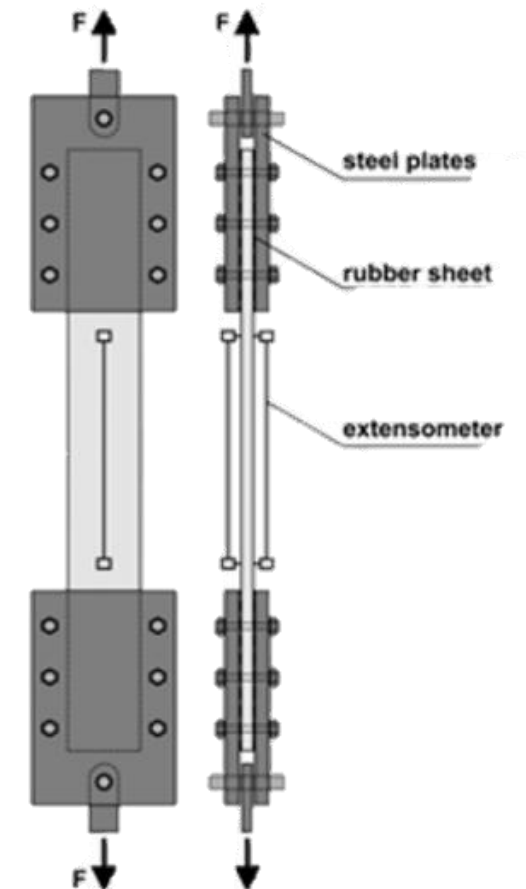
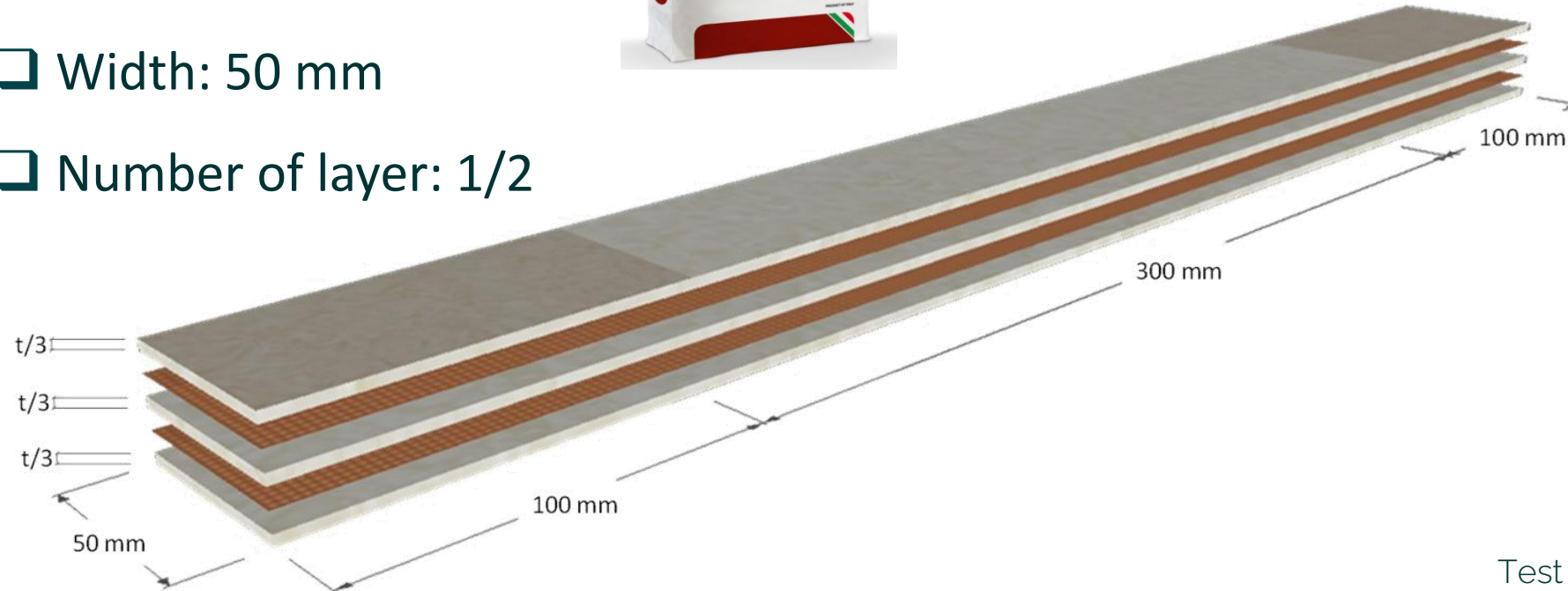
- ❑ Natural fibre: Flax
- ❑ Free length: 300 mm
- ❑ Gauge length: 500 mm
- ❑ Width: 50 mm
- ❑ Number of layer: 1/2



Lime-based mortar

Compressive strength = 13 MPa

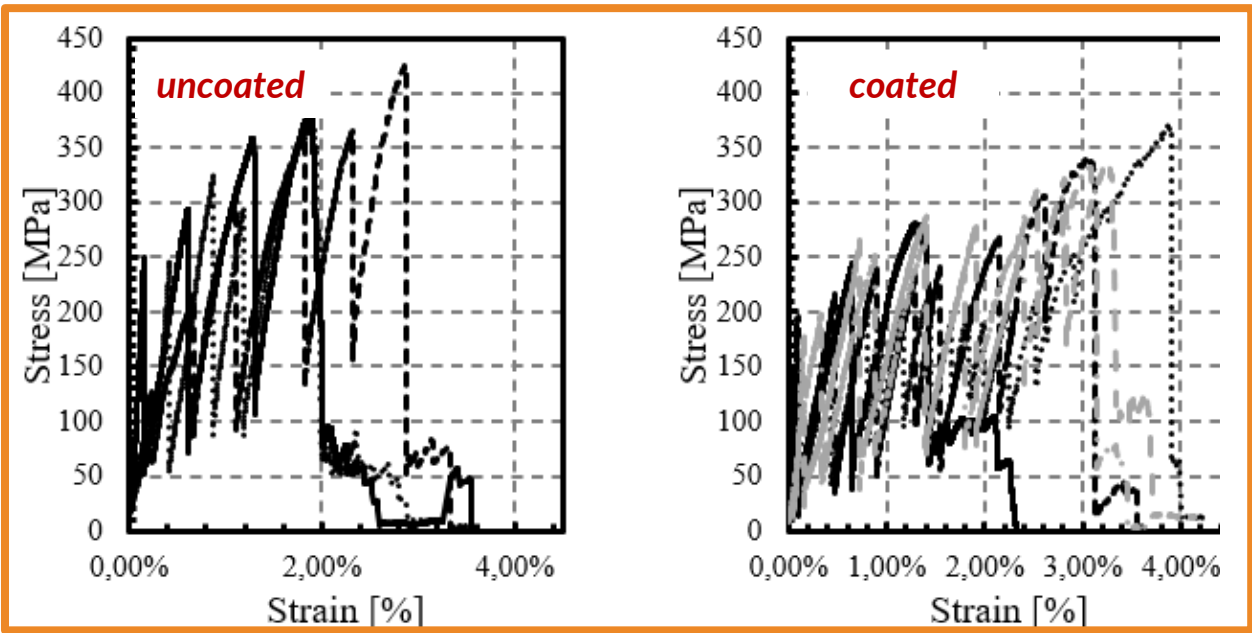
Flexural Strength = 4.50 MPa



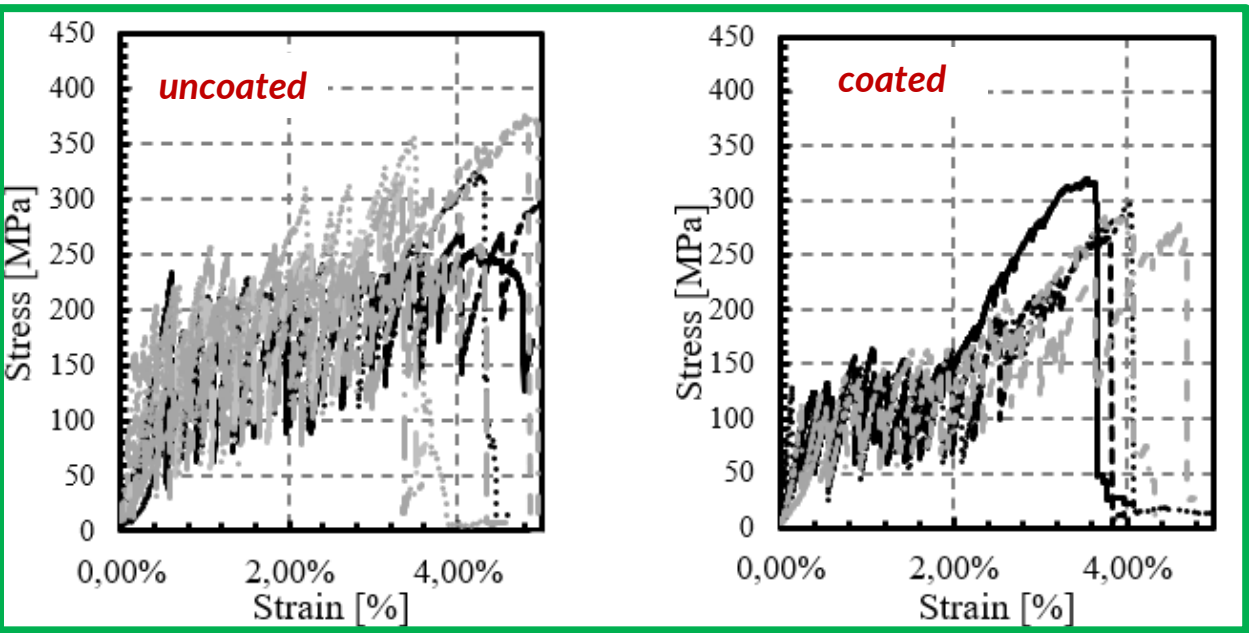
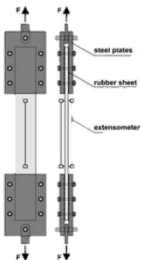
Test setup for FRCC samples (RILEM, 2016)

PLA coating optimisation

Stress-Strain response under tensile loads

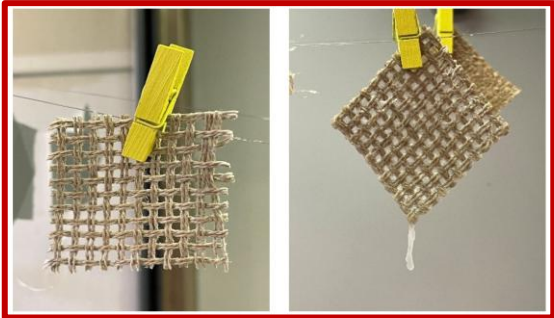


Flax TRM – 1 layer



Flax TRM – 2 layers

PLA coating



Overview

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FRCM system and application

Structural response of masonry panels reinforced with natural FRCM systems

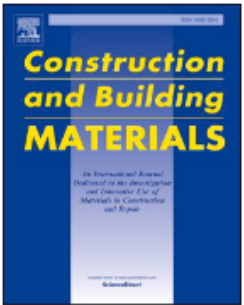
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Experimental study on shear behavior of masonry walls strengthened by bio-coated lime-based flax-TRM systems

Eduardo Sellitto ^a , Rosario Lombardi ^a, Marco Pepe ^{a,b,*}, Carmine Lima ^a, Enzo Martinelli ^a

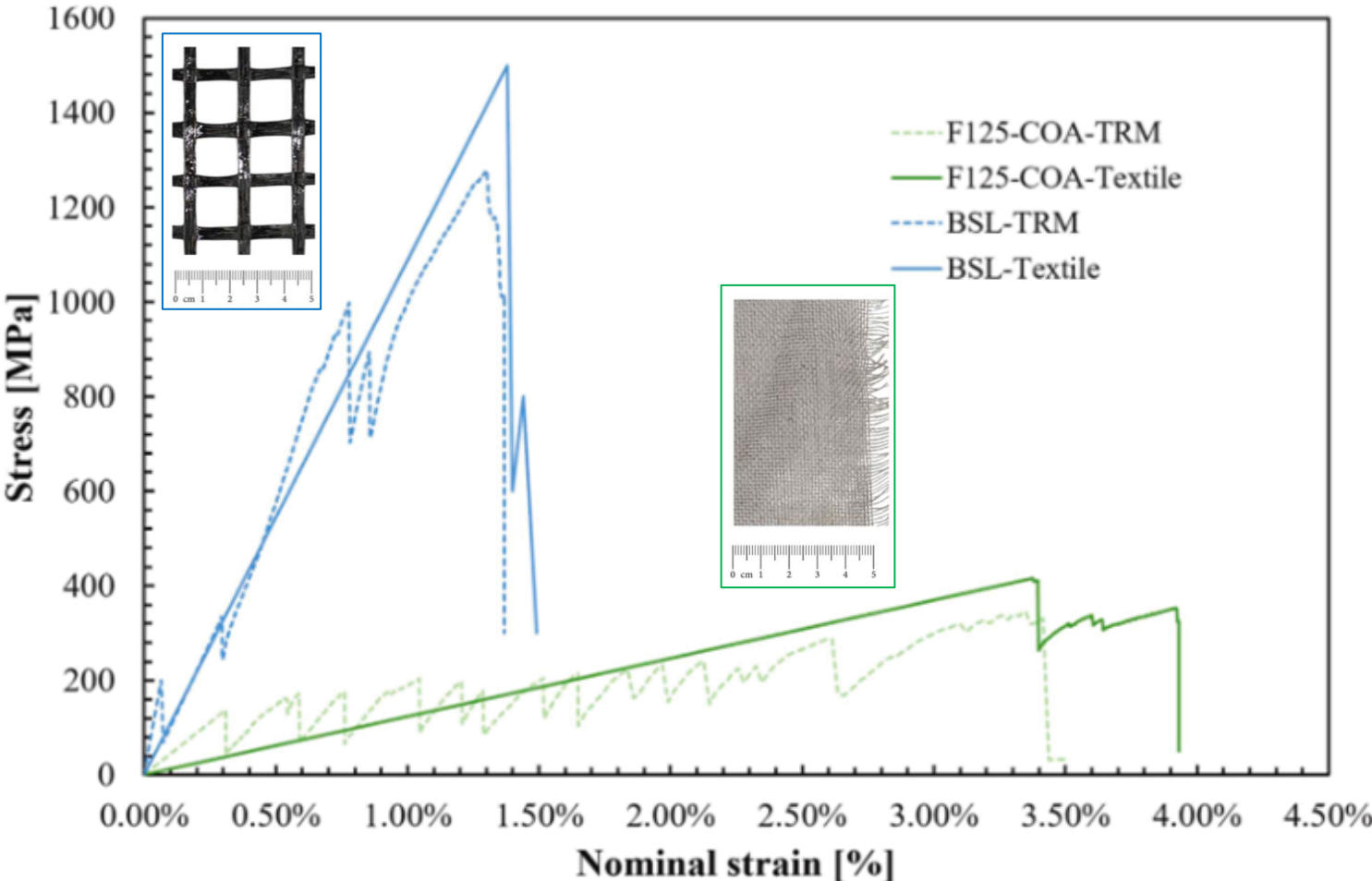
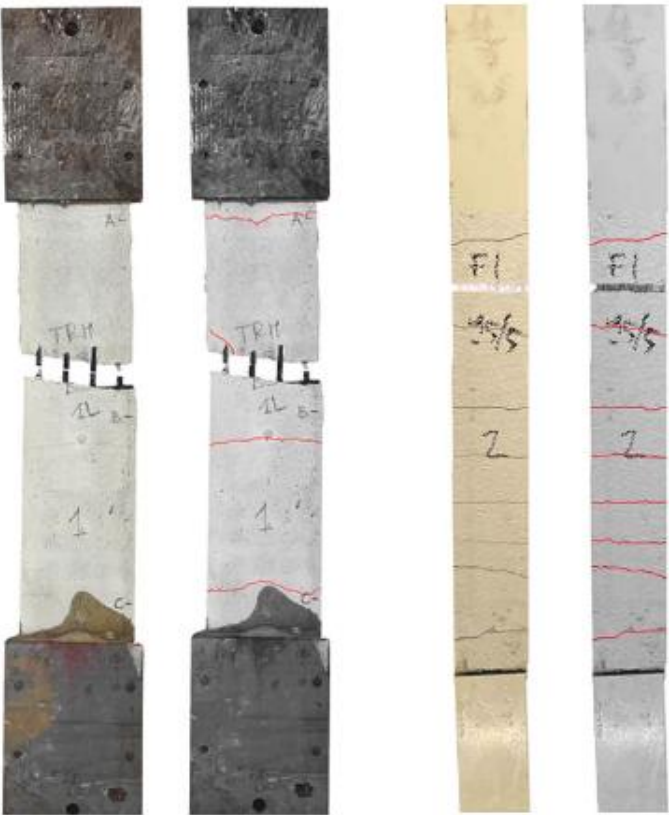
^a Department of Civil Engineering, University of Salerno, via Giovanni Paolo II 132, Fisciano, SA 84084, Italy

^b TESIS srl, Piazza Vittorio Emanuele 10, Fisciano, SA 84084, Italy

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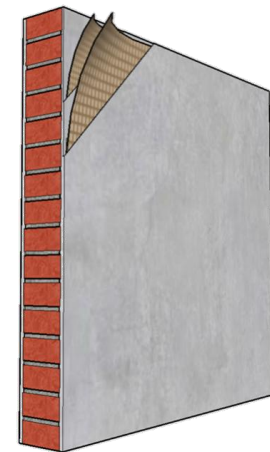
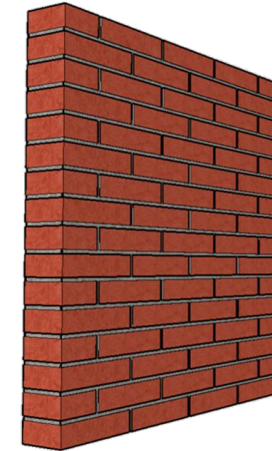
FCRM system and application

Tensile response of Basal and Flax FRCM systems



FCRM system and application

Diagonal-Compression tests



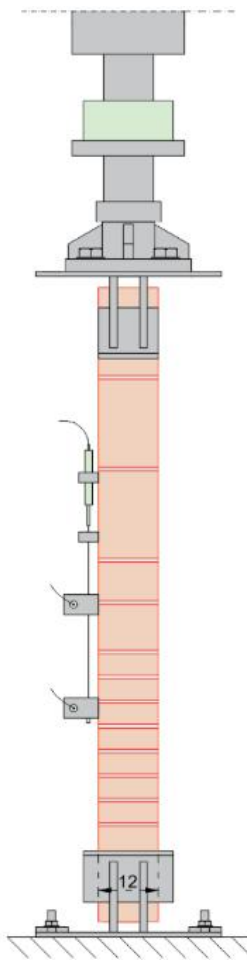
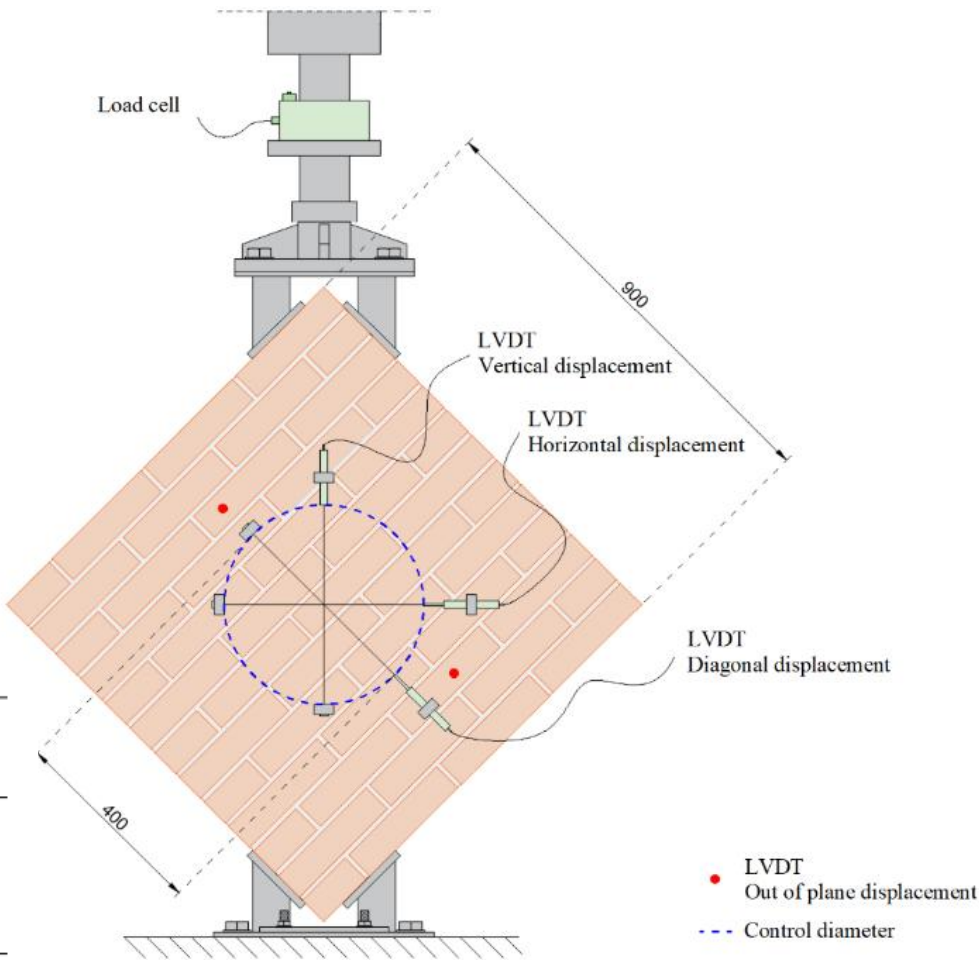
FCRM system and application

Diagonal-Compression tests



Serie	#Specimen	Masonry type	Size wall t x w x h [mm³]
REF	4	Clay solid brick	120 × 900 x 900
BSL	4	Clay solid brick	120 × 900 x 900
F125-COA	4	Clay solid brick	120 × 900 x 900

Serie	Number of layer and type of reinforced	Mortar (Masonry - TRM)	Average TRM thickness [mm]
REF	-	NHL 3.5	-
BSL	1 Layer Basalt	NHL 3.5 - Fiber reinforced NHL 3.5	25 (12.50 per side)
F125-COA	2 Layers Flax coated	NHL 3.5 - Fiber reinforced NHL 3.5	23 (11.50 per side)

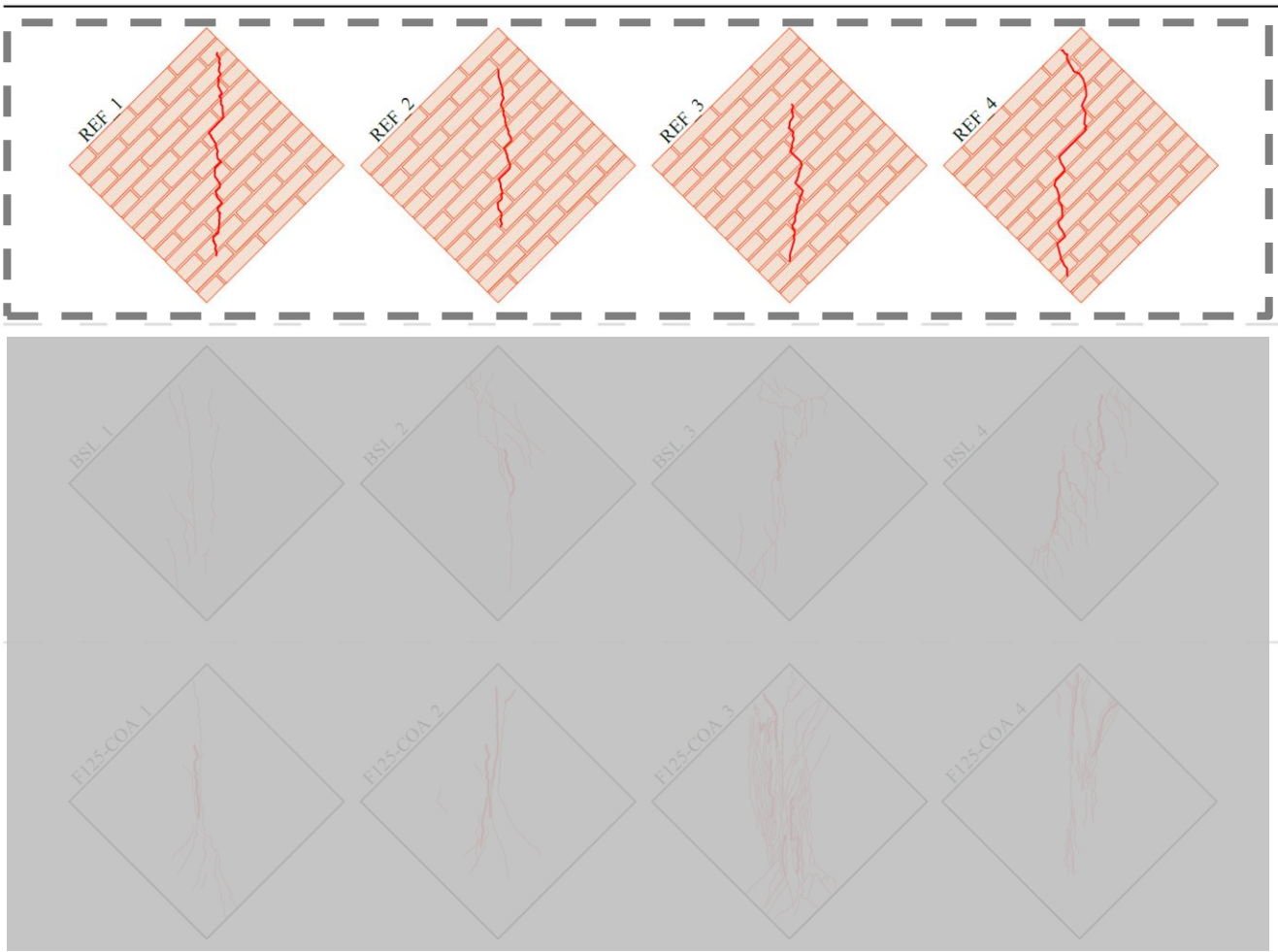


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FCRM system and application

Diagonal-Compression tests

Unreinforced samples

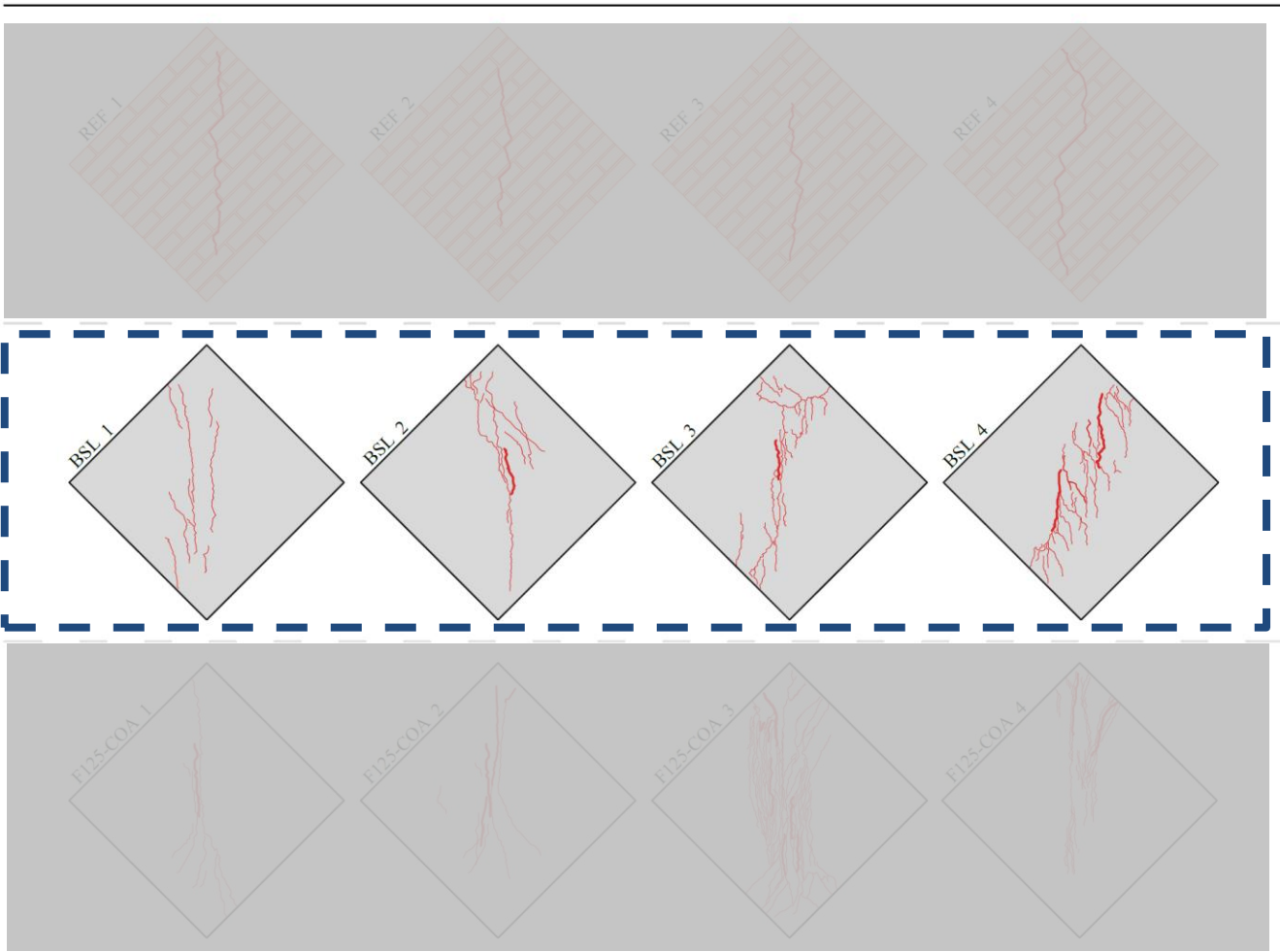
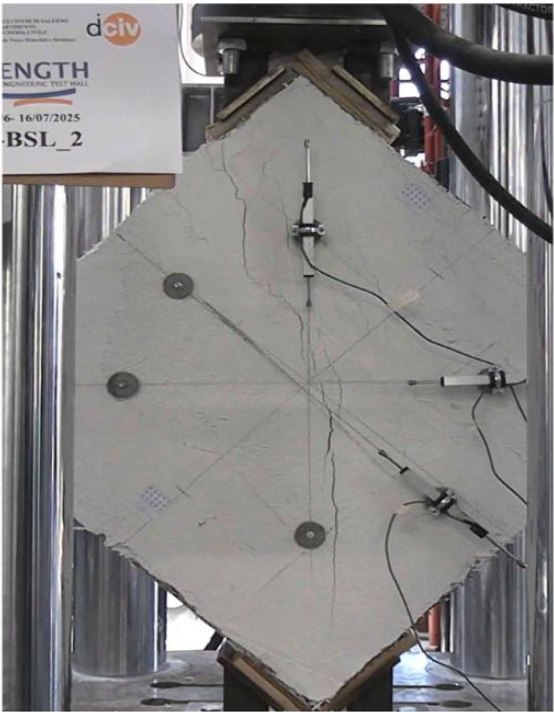


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FCRM system and application

Diagonal-Compression tests

1 layer of BASALT FRCM

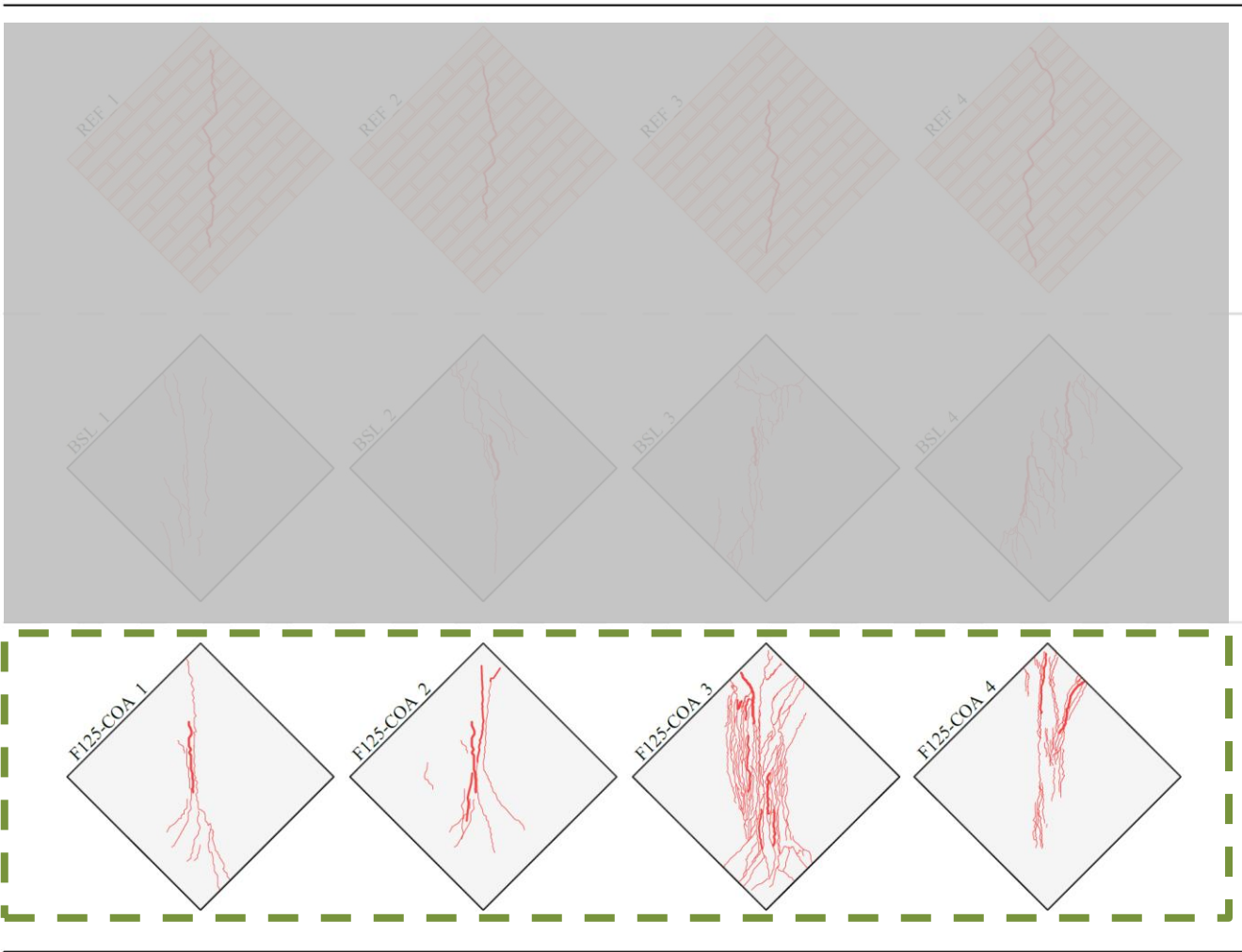
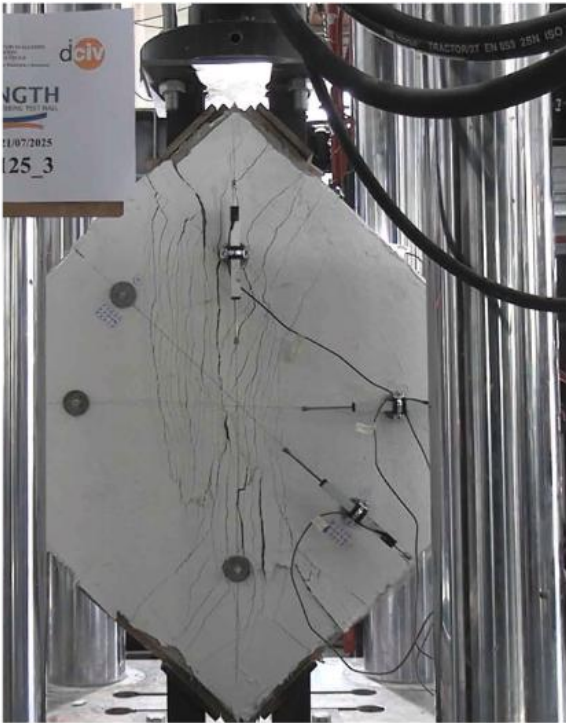


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FCRM system and application

Diagonal-Compression tests

2 layers of FLAX FRCM

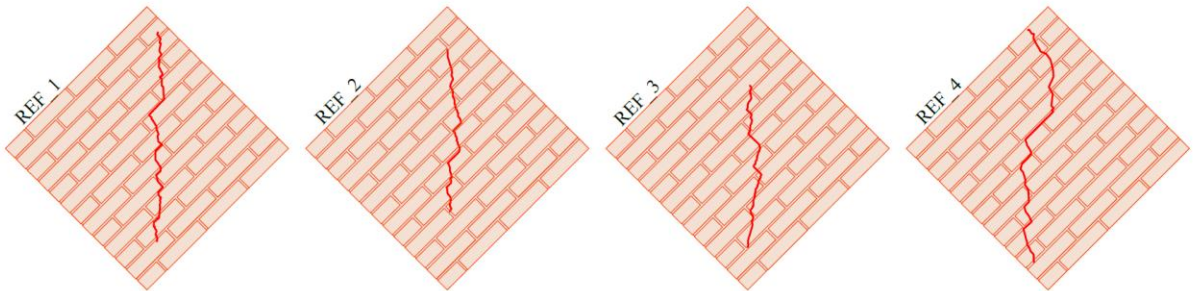
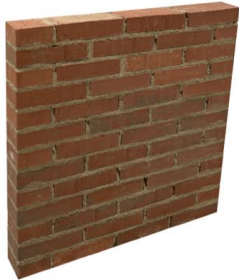


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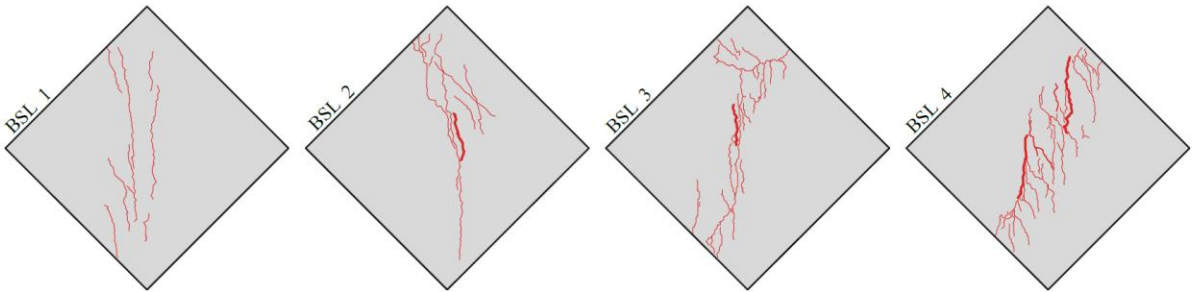
FCRM system and application

Diagonal-Compression tests

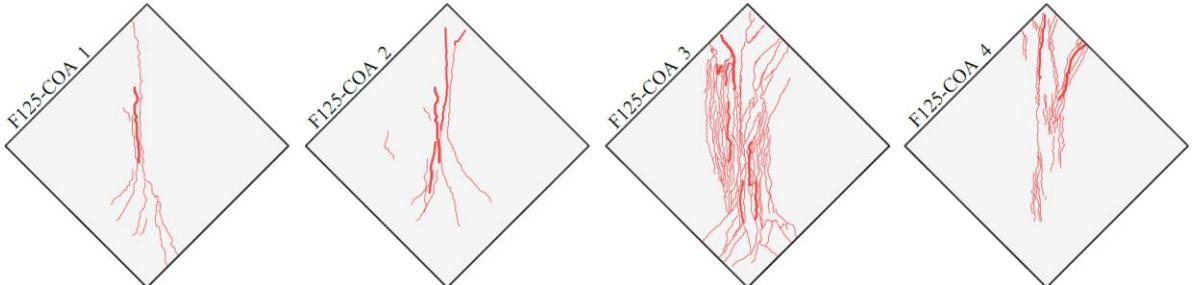
Unreinforced samples



1 layer of BASALT FRCM

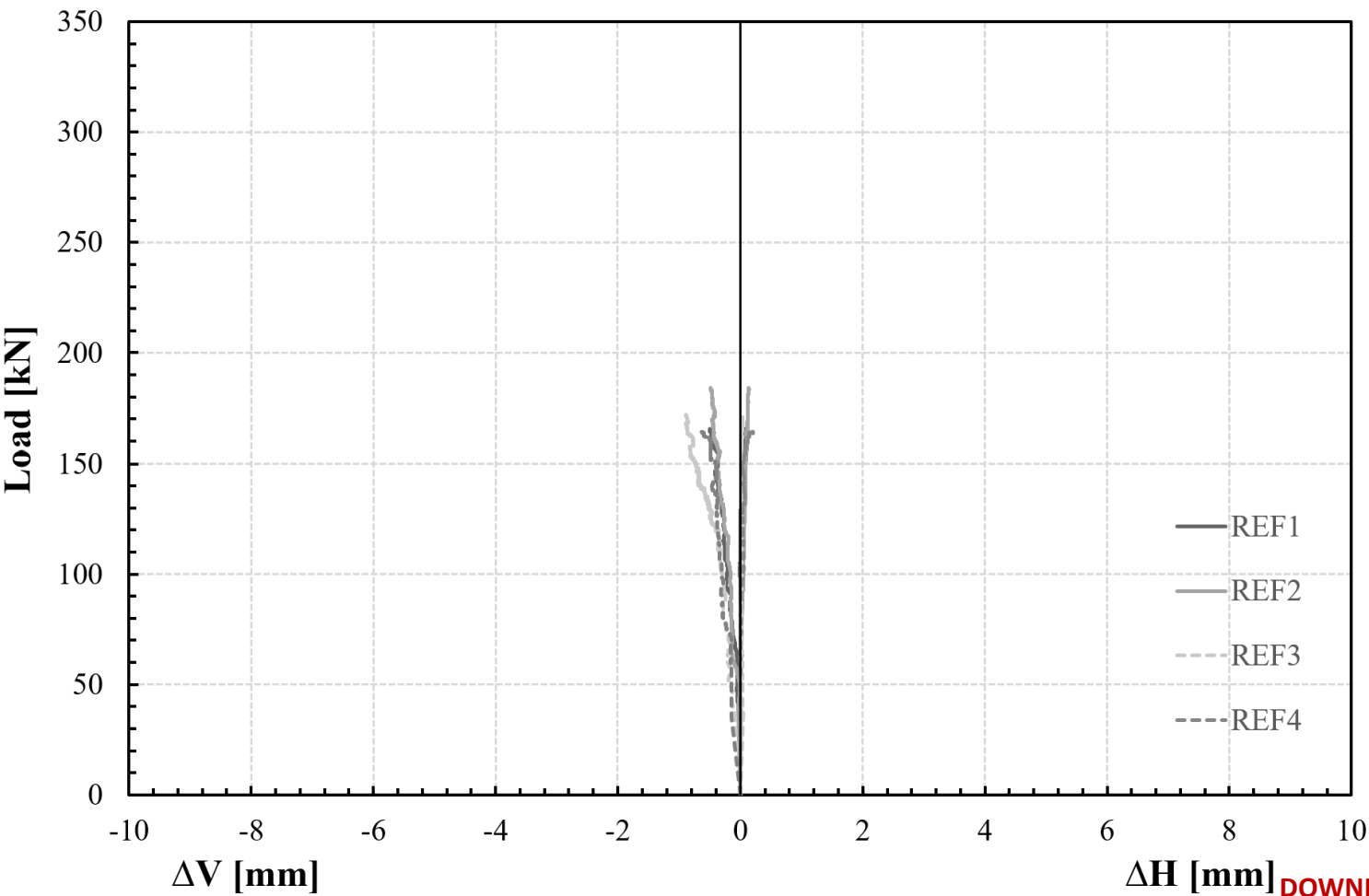


2 layers of FLAX FRCM



FCRM system and application

Load-Vertical/Horizontal displacements curves for Diagonal-Compression tests

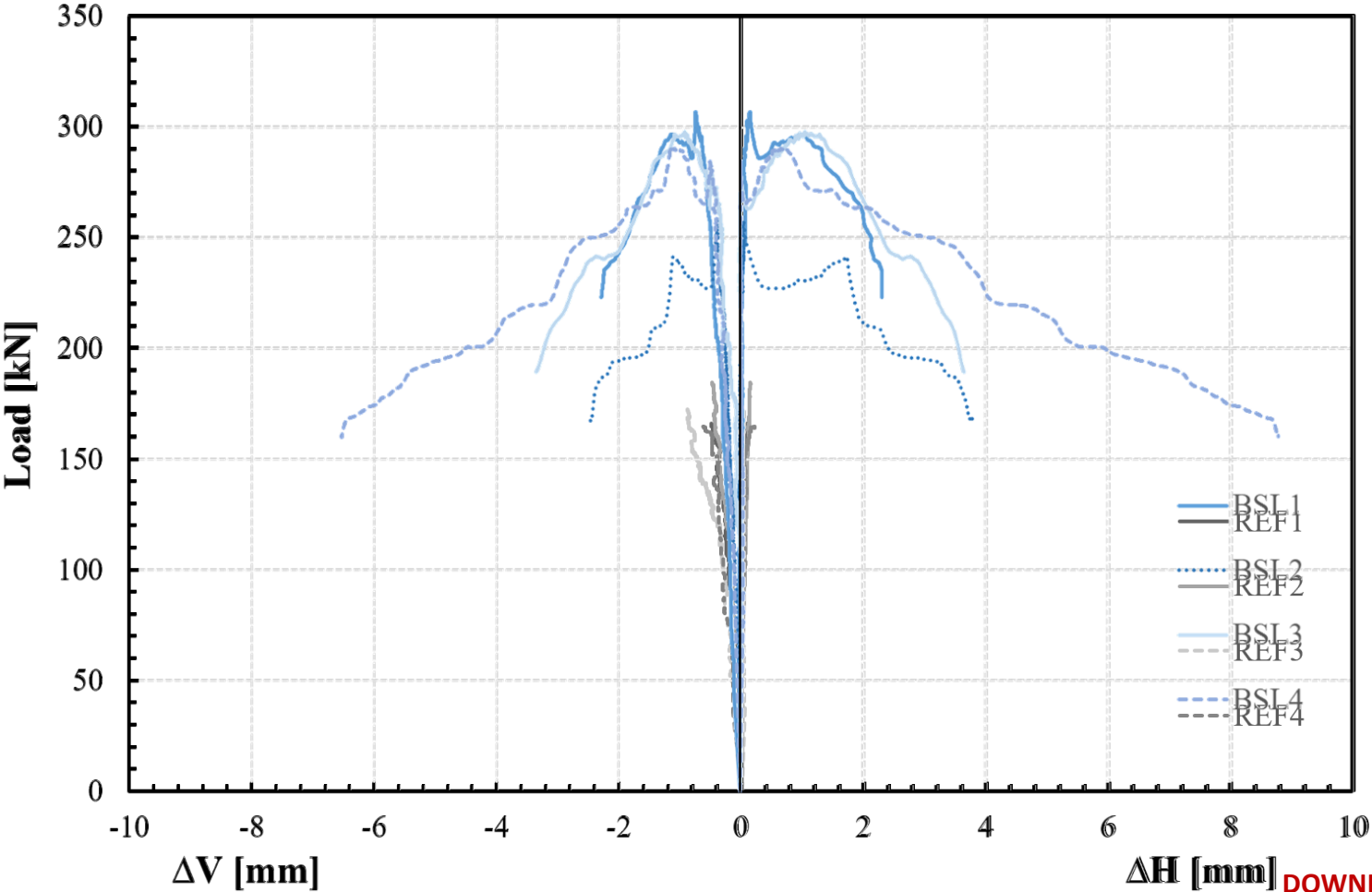


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REF_1	166	1.08	0.012	613	55	-
REF_2	184	1.21	0.013	756	55	-
REF_3	172	1.13	0.002	581	97	-
REF_4	165	1.08	0.002	851	61	-
BSL_1	307	1.68	0.011	1350	135	420
BSL_2	258	1.41	0.016	1900	63	437
BSL_3	298	1.62	0.018	846	225	606
BSL_4	291	1.57	0.038	1374	274	1161
F125-COA_1	263	1.45	0.012	1725	72	299
F125-COA_2	264	1.46	0.009	1472	61	176
F125-COA_3	233	1.29	0.032	1200	64	2319
F125-COA_4	263	1.46	0.012	1011	136	62

Unreinforced samples

FCRM system and application

Load-Vertical/Horizontal displacements curves for Diagonal-Compression tests



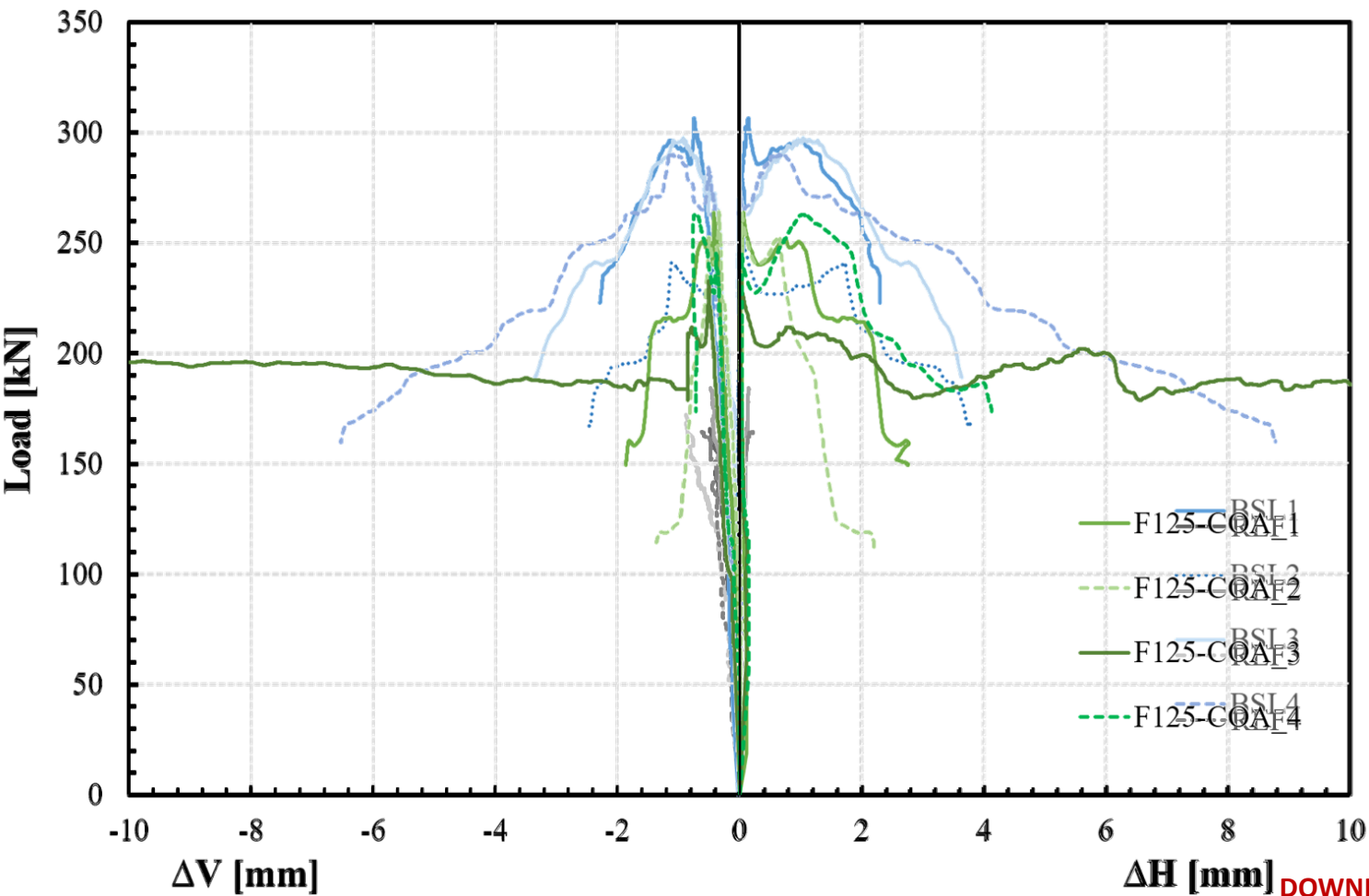
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Unreinforced samples

Masonry walls reinforced with
1 layer of BASALT FRCM

FCRM system and application

Load-Vertical/Horizontal displacements curves for Diagonal-Compression tests



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Unreinforced samples

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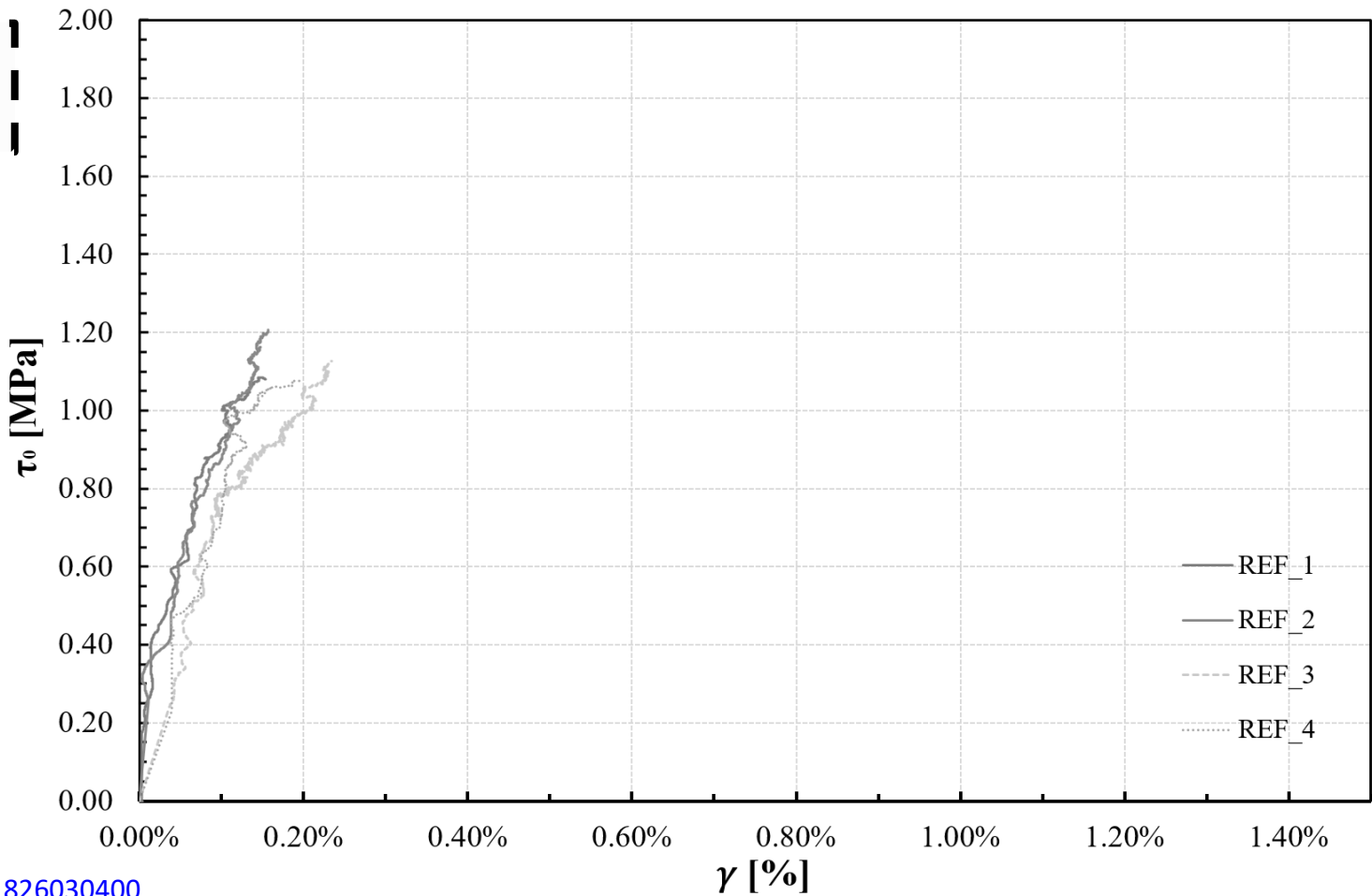
Masonry walls reinforced with
2 layers of FLAX FRCM

FCRM system and application

Shear stress - shear nominal strain curves for Diagonal-Compression tests

Specimen	P _{peak} [kN]	τ _{0,peak} [MPa]	γ _{peak} [%]	G [MPa]	Γ ₁ [J]	Γ ₂ [J]
REF_1	166	1.08	0.012	613	55	-
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F125-COA_2	264	1.46	0.009	1472	61	176
F125-COA_3	233	1.29	0.032	1200	64	2319
F125-COA_4	263	1.46	0.012	1011	136	62

Unreinforced samples



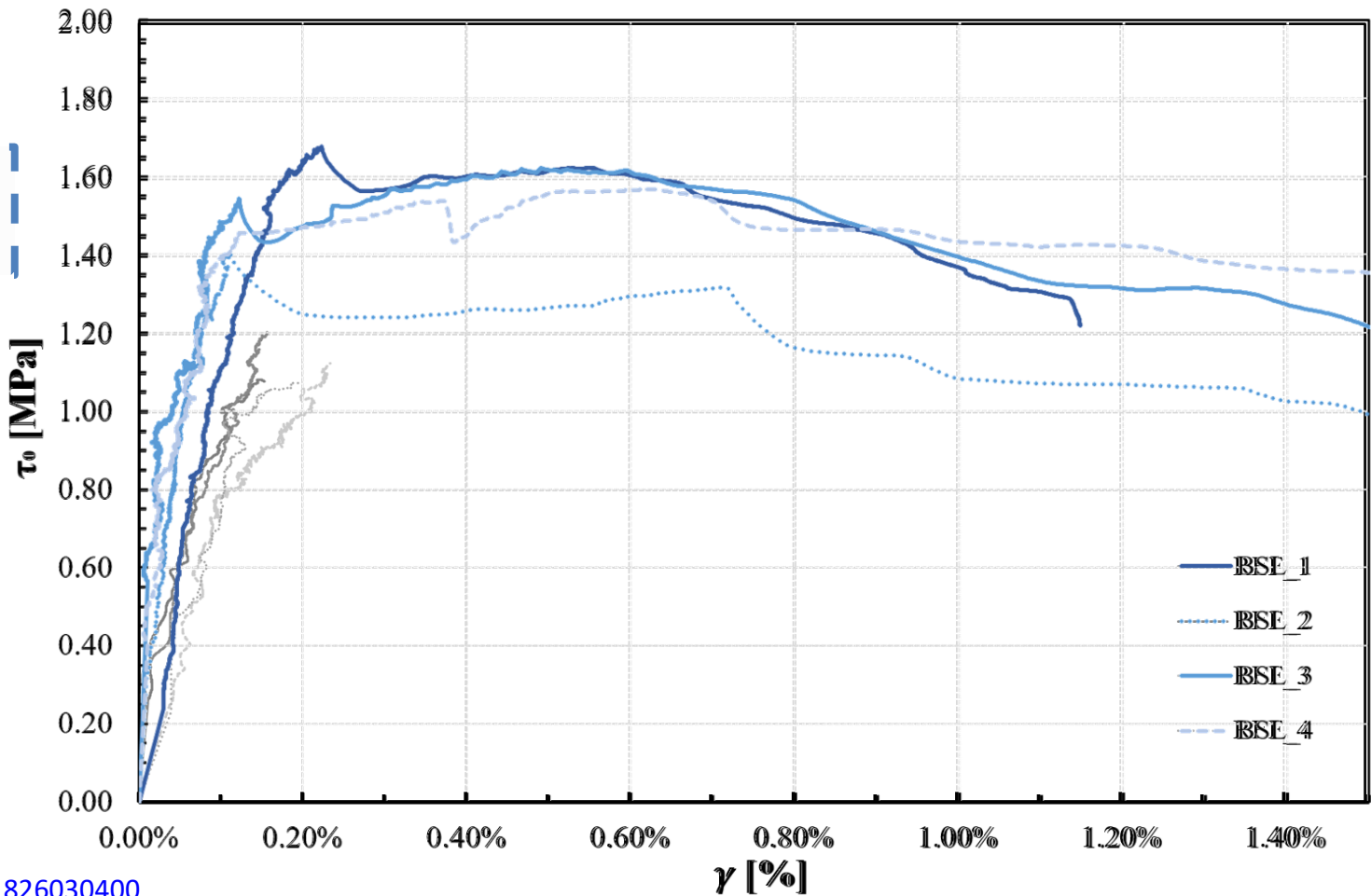
FCRM system and application

Shear stress - shear nominal strain curves for Diagonal-Compression tests

Specimen	P _{peak} [kN]	τ _{0,peak} [MPa]	γ _{peak} [%]	G [MPa]	Γ ₁ [J]	Γ ₂ [J]
REF_1	166	1.08	0.012	613	55	-
REF_2	184	1.21	0.013	756	55	-
REF_3	172	1.13	0.002	581	97	-
REF_4	165	1.08	0.002	851	61	-
BSL_1	307	1.68	0.011	1350	135	420
BSL_2	258	1.41	0.016	1900	63	437
BSL_3	298	1.62	0.018	846	225	606
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F125-COA_3	233	1.29	0.032	1200	64	2319
F125-COA_4	263	1.46	0.012	1011	136	62

Unreinforced samples

Masonry walls reinforced with
1 layer of BASALT FRCM



FCRM system and application

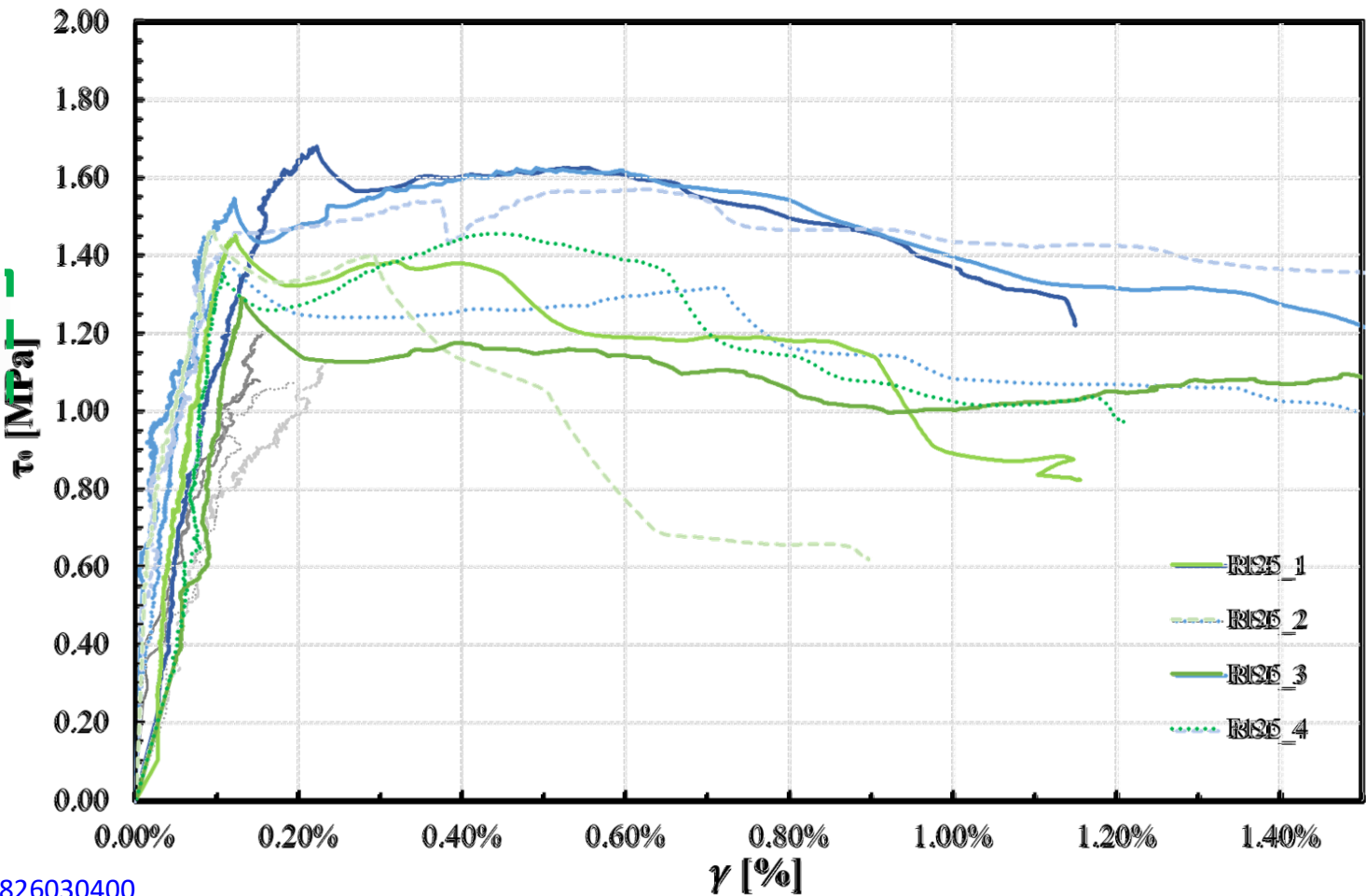
Shear stress - shear nominal strain curves for Diagonal-Compression tests

Specimen	P _{peak} [kN]	τ _{0,peak} [MPa]	γ _{peak} [%]	G [MPa]	Γ ₁ [J]	Γ ₂ [J]
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Unreinforced samples

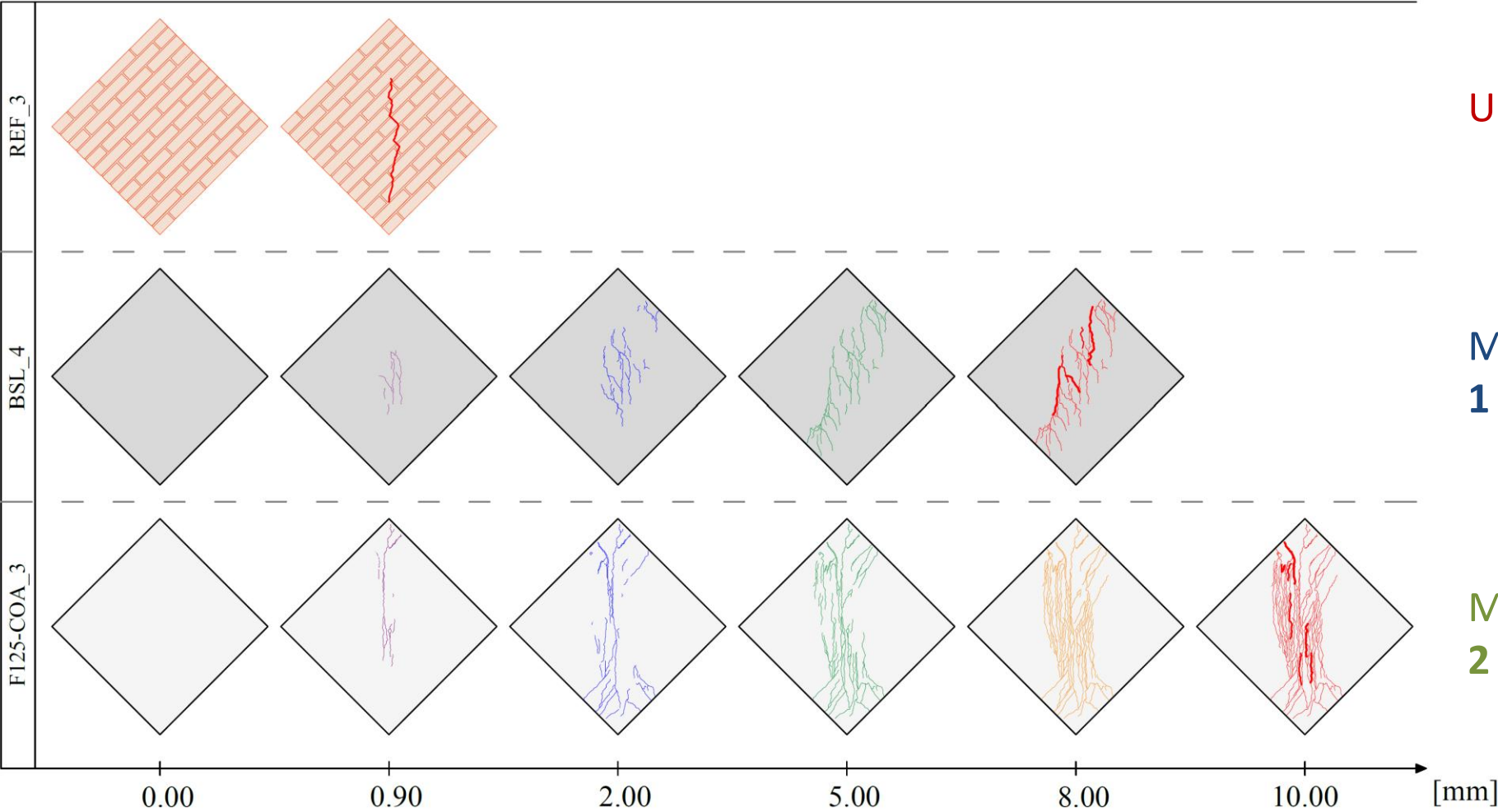
Masonry walls reinforced with
1 layer of **BASALT FRCM**

Masonry walls reinforced with
2 layers of **FLAX FRCM**



FCRM system and application

Crack development during Diagonal-Compression tests



Unreinforced samples

Masonry walls reinforced with
1 layer of BASALT FRCM

Masonry walls reinforced with
2 layers of FLAX FRCM

FCRM system and application

Dissipated energy and evaluation of FRCM system shear strength capacity

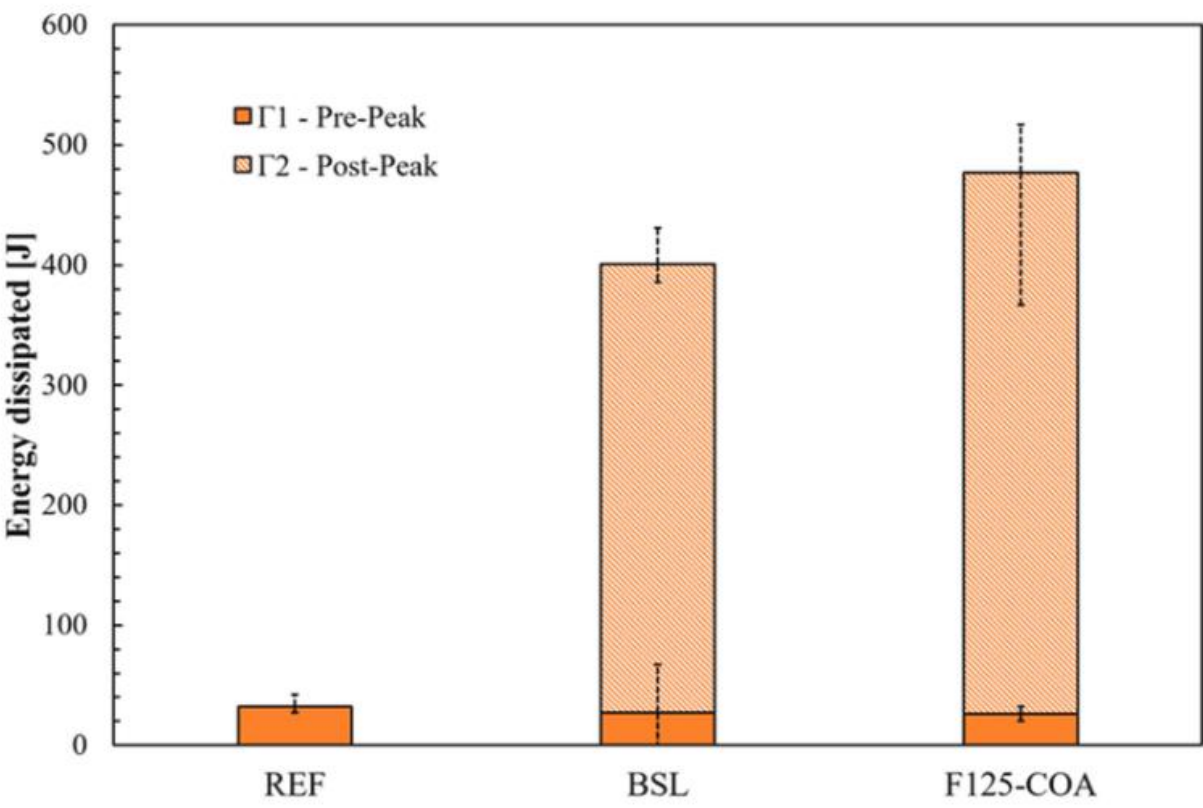


Fig. 14. Diagonal compression test: average values of energy dissipated for every series.

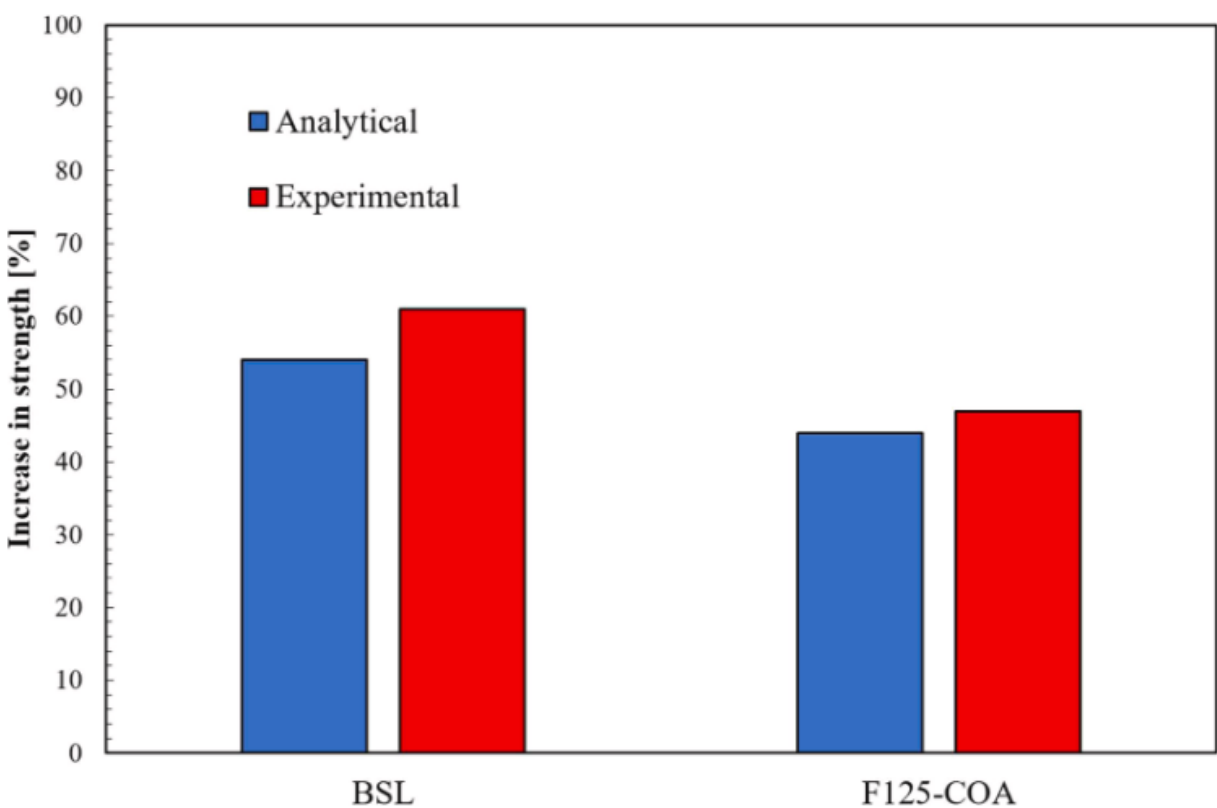


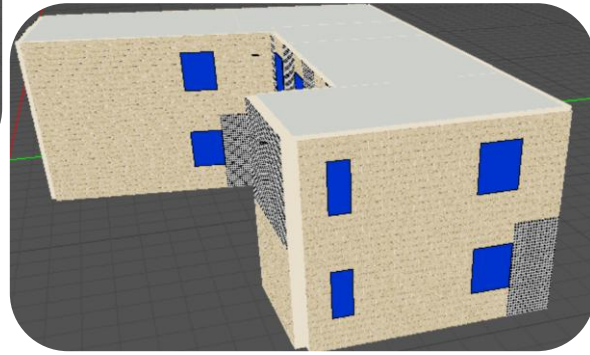
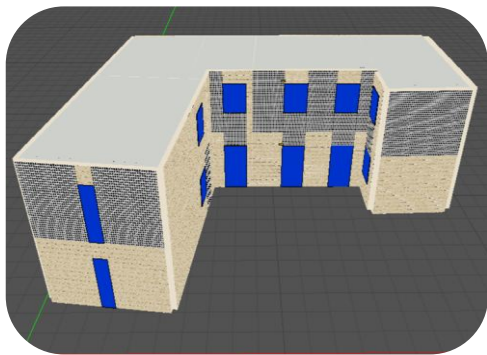
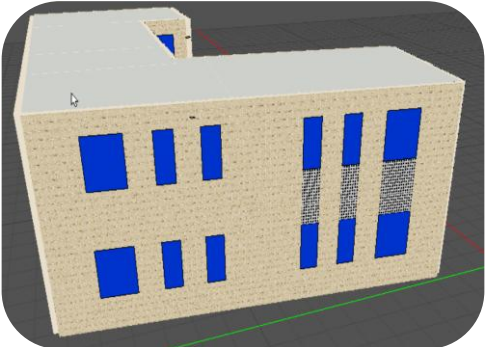
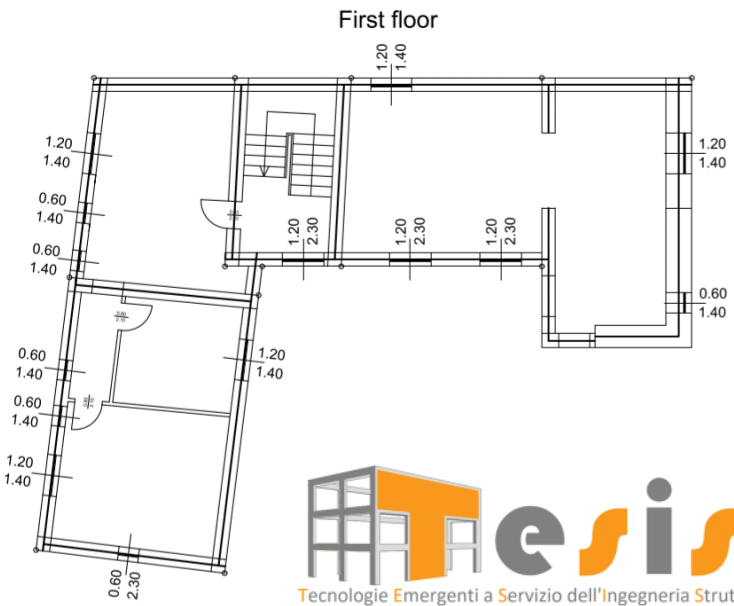
Fig. 15. Comparison of strength increase from standard models and experimental results for BSL and F125-COA series.

FCRM system and application

Global response evaluation

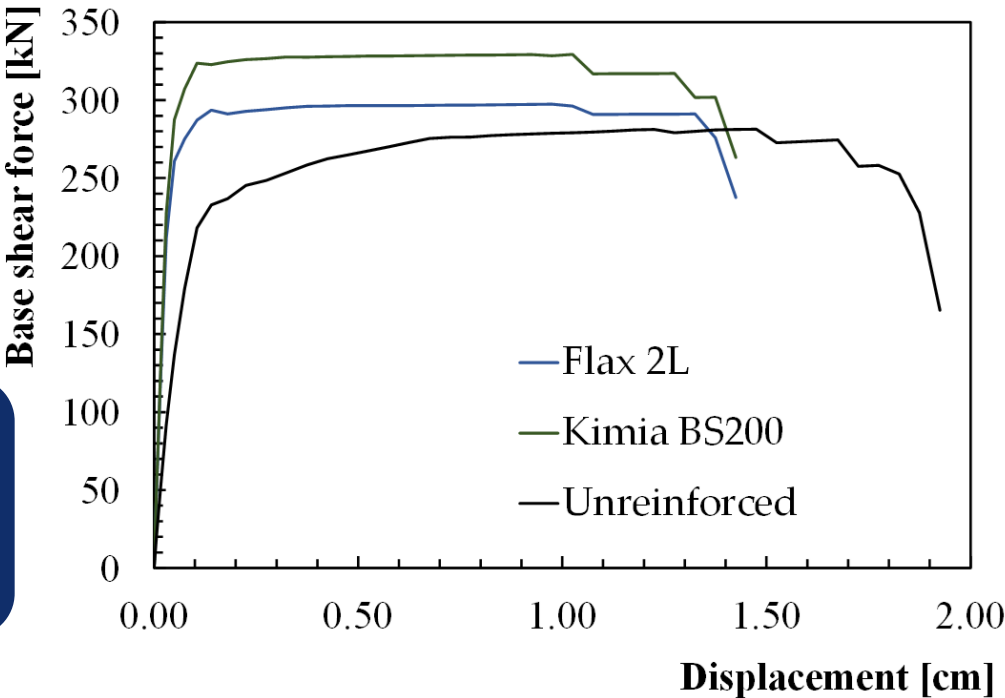
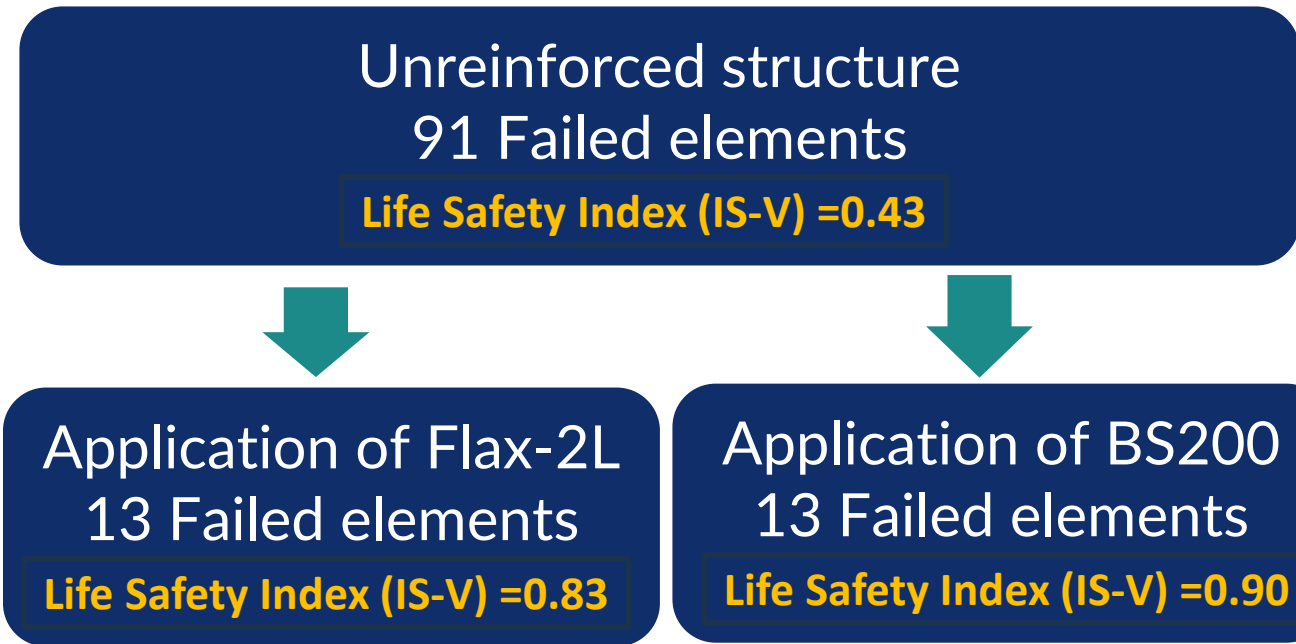
➡ Application of Flax-2L

➡ Application of commercial product:
Kimia BS200 (Basalt)

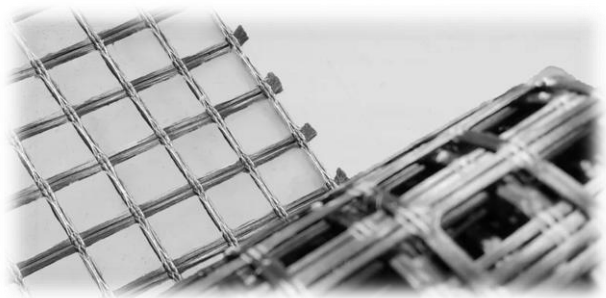
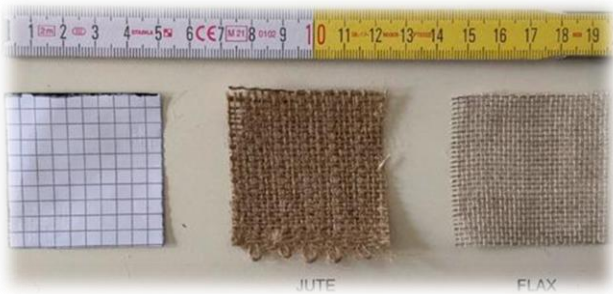


FCRM system and application

Global response evaluation



Pushover curves for a single seismic action



Overview

- ☐ Introduction
- ☐ FRCM system optimisation
- ☐ Structural scale applications
- ☒ **Conclusion and future development**

Conclusions and future development

Conclusions

- The **high** (above 1%) **reinforcement ratio** for both analysed TRM systems demonstrates the composite behaviour of the **improved** samples tested under **tensile loads**;
- **Coating** application increase the **physical/mechanical properties** of natural fibers;
- **FRCMs** with **coated** fibers presents a more homogeneous behaviour, number of **cracks** and a more evident **post-cracking zone** in the stress-strain curves;
- In the **diagonal compression tests**, the structural response of masonry panels reinforced with 2 layers of coated flax textile is comparable with commercial products made with basalt textile with a **significant post-peak** phase capable of dissipating a large amount of energy (almost 10 times that dissipated in the pre-peak phase), confirming a notable increase in ductility;

Further developments

IntegraTRM – PRIN PNRR project



IntegraTRM

Integrated seismic and thermal upgrading of existing masonry buildings through a novel sustainable Textile-Reinforced Mortar system

The IntegraTRM project aims at formulating an **efficient and sustainable solution for coupled thermal and seismic upgrading of existing constructions**, with emphasis on masonry buildings.

It aims at formulating the composition of a composite Textile Reinforced Mortar (TRM) system characterized by an “optimized” performance in terms of both **structural strengthening** (especially towards the effect of earthquake-induced actions) and **thermal insulation**, which are of utmost importance as possible actions intended at reducing both seismic risk and energy demand of the built environment.

The formulation of the TRM system under consideration is based on the use of “environmentally-friendly” constituents. Specifically, a significant fraction of **recycled aggregates**, coming from construction and demolition waste, are being considered for the mixture proportioning of the mortar matrix. Furthermore, **renewable bio-based constituents**, such as vegetable fibers and fabrics, are being employed to achieve both mechanical resistance and thermal insulation potential.

Further developments

IntegraTRM – PRIN PNRR project



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Textile reinforcement mortar: Natural fiber TRM system for integrated (structural and thermal) retrofitting

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Maria Francesca Sabbà^b, Marco Pepe^c , Flavio Stochino^a 

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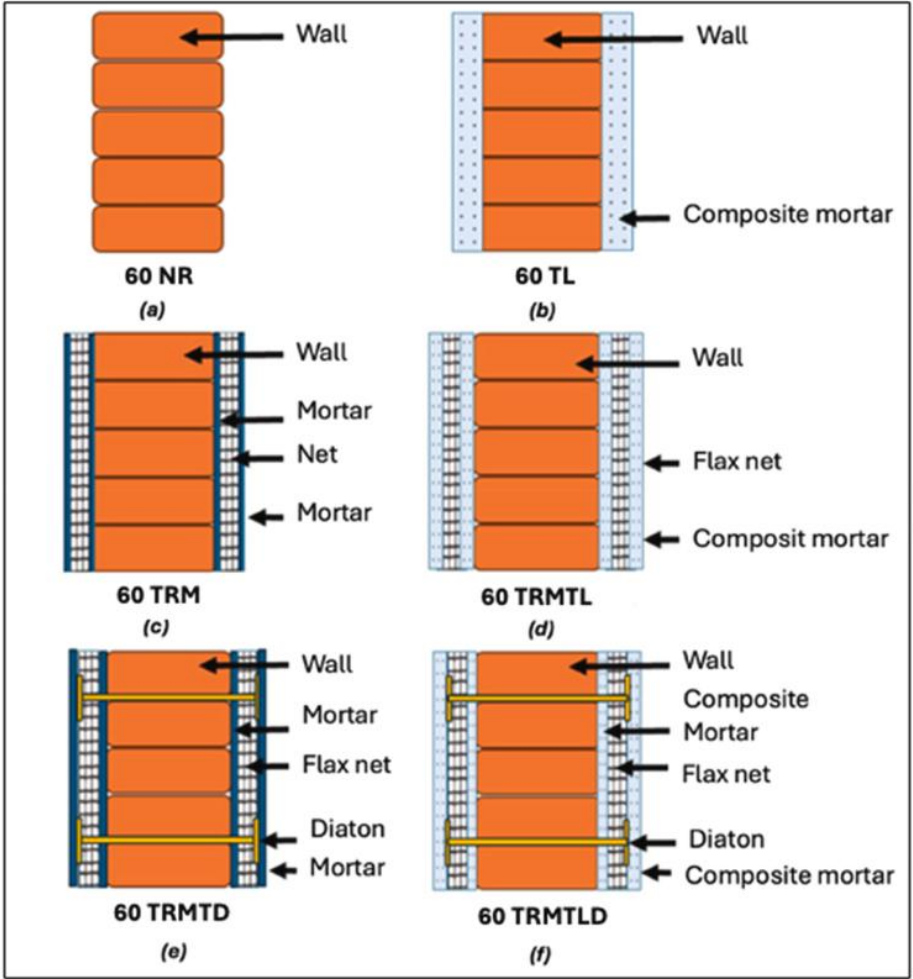
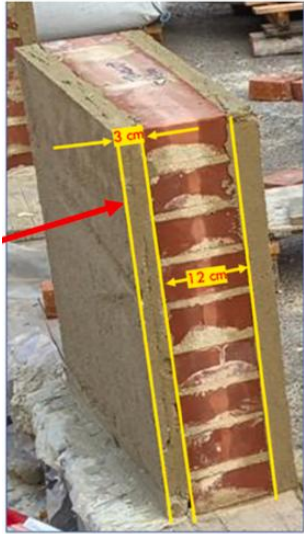
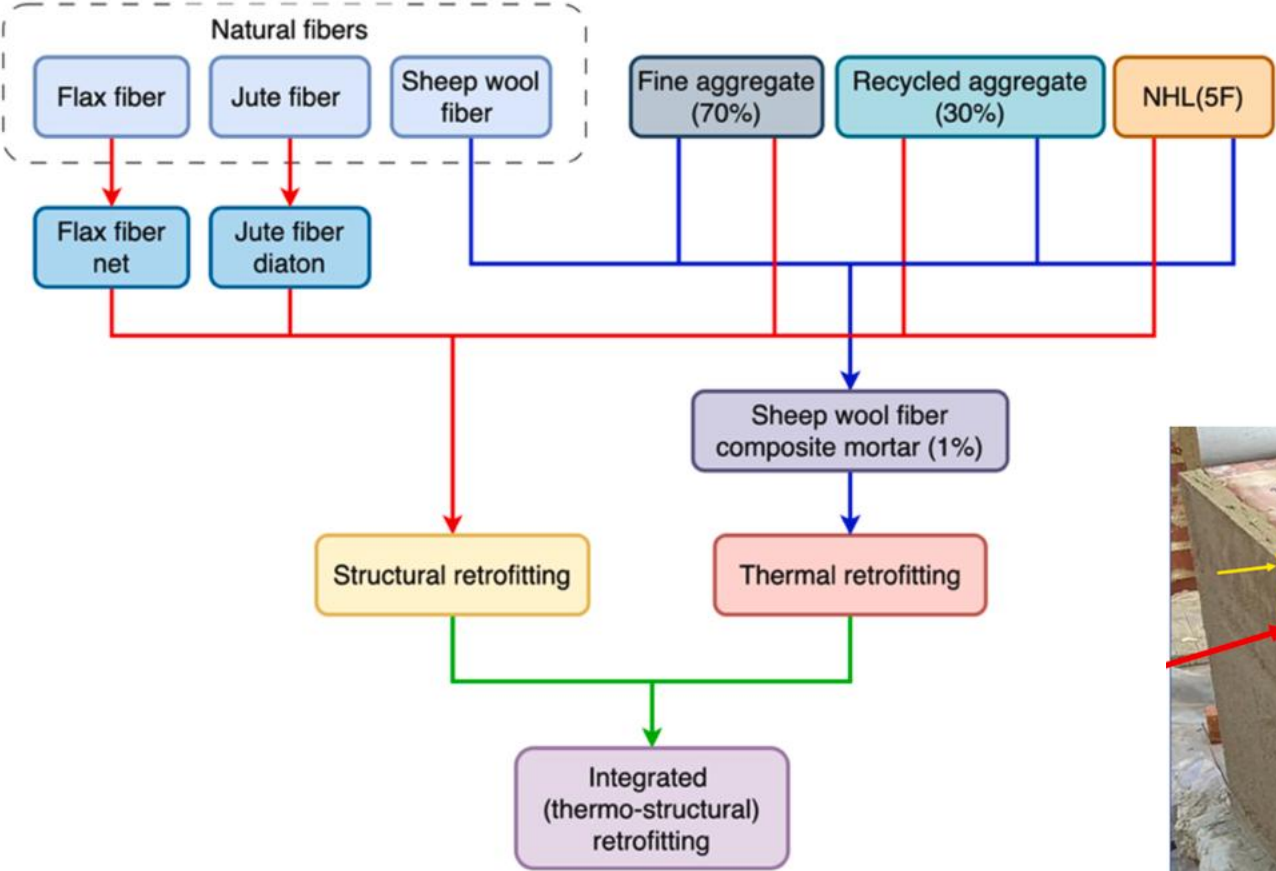
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^c Department of Civil Engineering, University of Salerno, via Giovanni Paolo II n.132, Fisciano, SA, 84084, Italy

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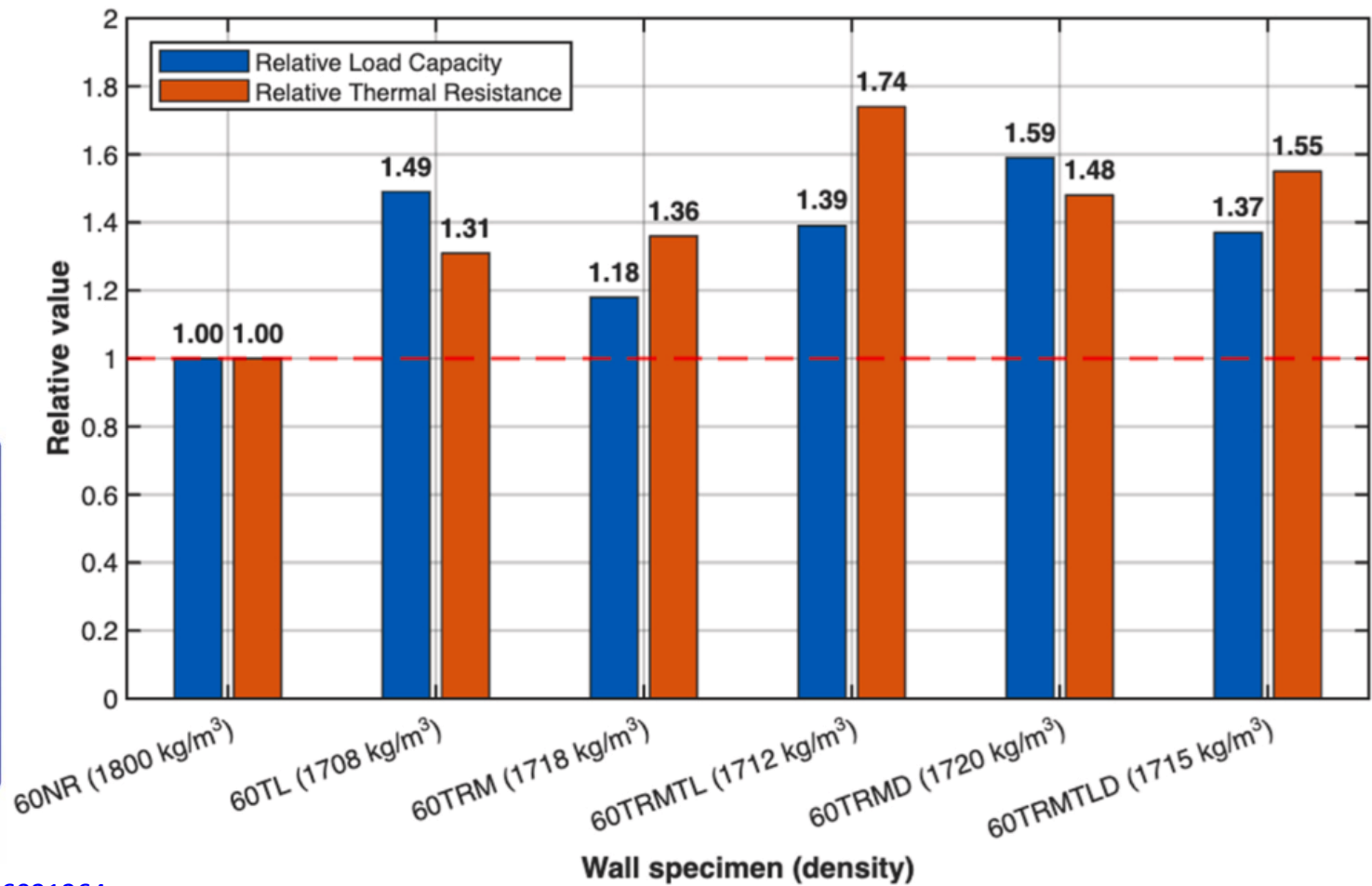
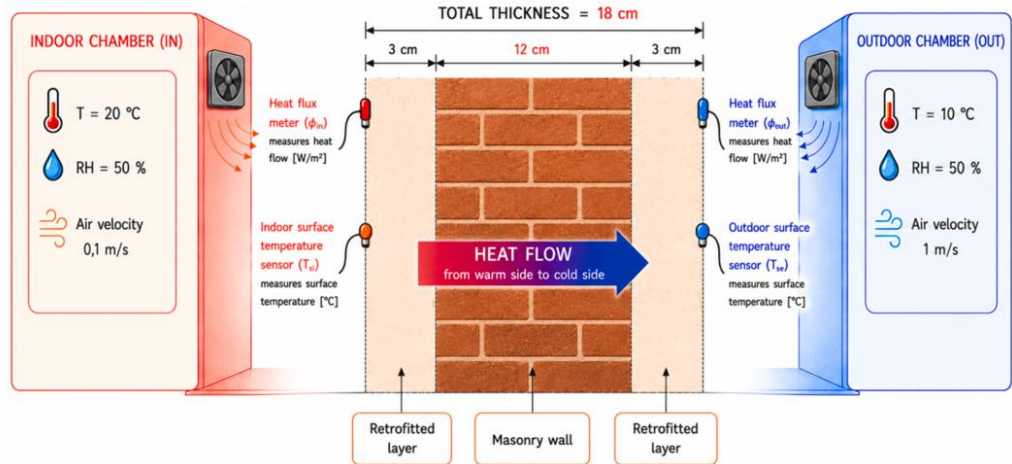
Further developments

IntegraTRM – PRIN PNRR project



Further developments

IntegraTRM – PRIN PNRR project

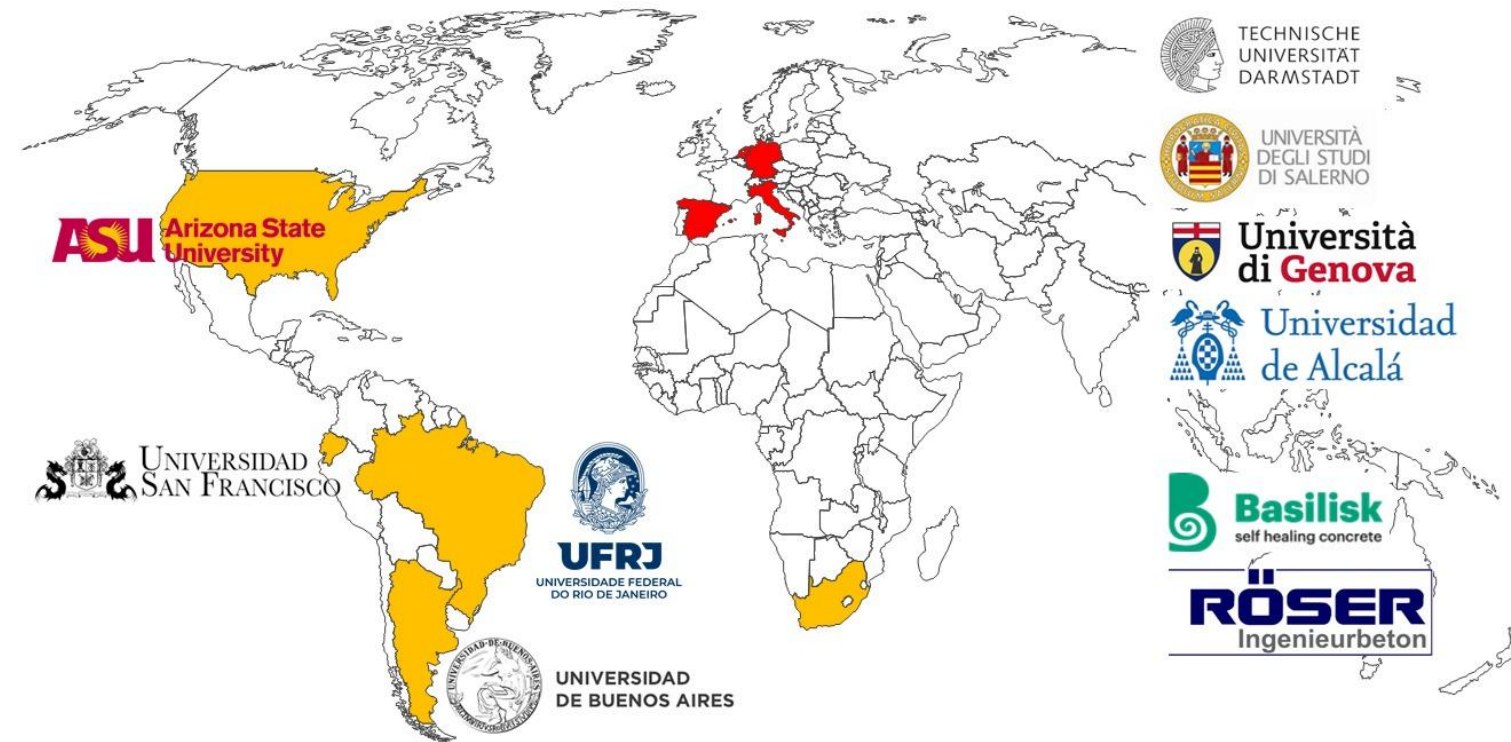


Future development

BEST – MSCA EU project



Bio-based Energy-efficient materials and Structures for Tomorrow



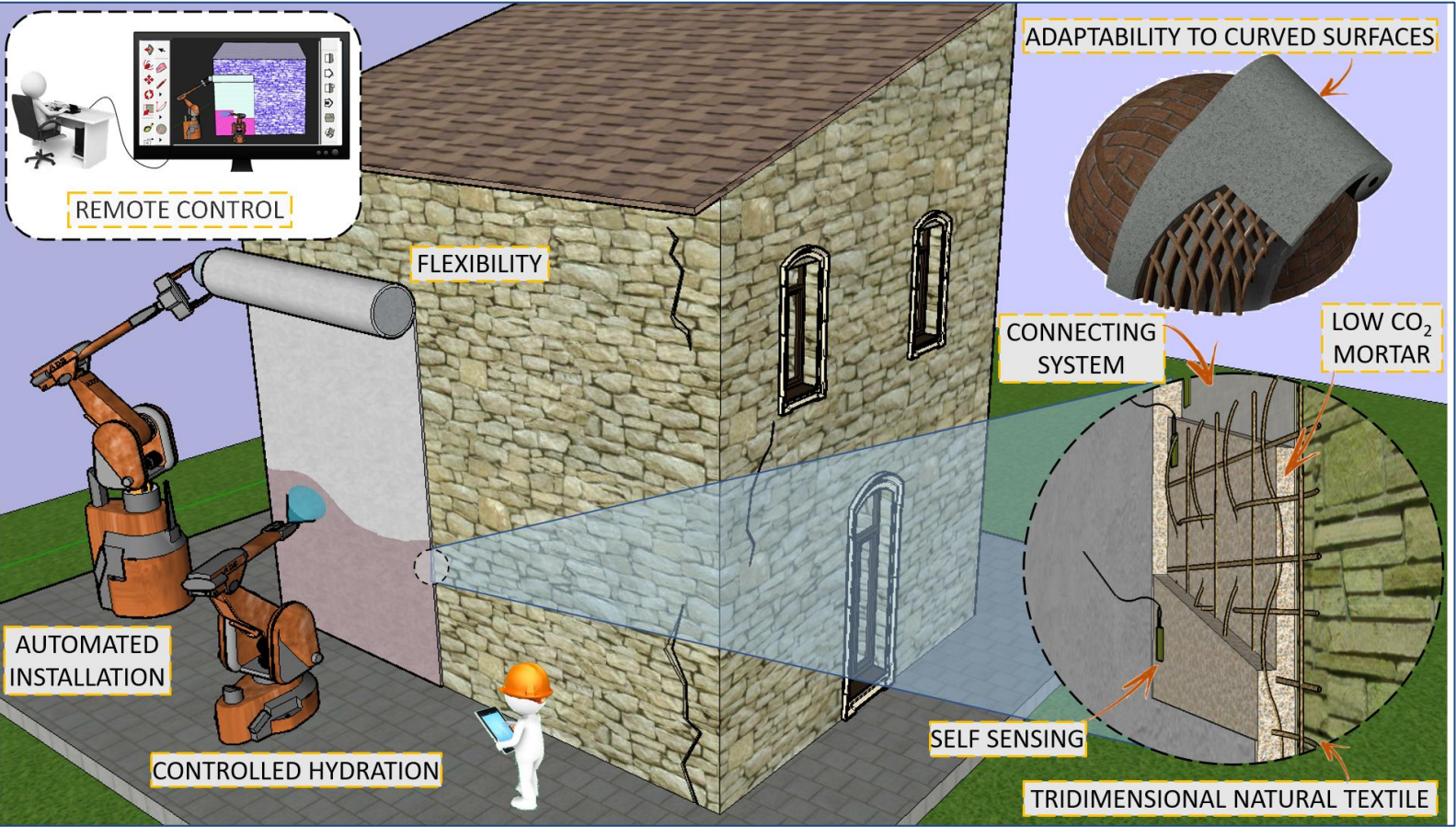
The project deals with bio-based materials:

- (i) **Fibres and fabrics of vegetal origin**, such as fibres obtained from leaves or stems of tropical plants, as well as fabrics made out of such fibres;
- (ii) **Bio- aggregates** obtained from waste and residuals of agricultural activities;
- (iii) **Self-healing agents** for concrete and other cement-based composites;
- (iv) **Supplementary cementitious materials** obtained by incinerating organic waste.

Future development

FISA 2023 – MaStRoNG project

Masonry Structures retrofitting through Robotized sustainable Next-Generation composites



Thanks for your attention