Blast and Fire Resistant Material

B A M

EXCELLENCE/0421/0137

DELIVERABLE D2.4

DISSEMINATION EVENT WITH LOCAL STAKEHOLDERS

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Project Information

Project Title	Blast and Fire Resistant Material
Project Acronym	BAM
Programme	EXCELLENCE HUBS
Grant Number	EXCELLENCE/0421/0137
Project Duration	01.04.2022 – 31.03.2024 (24 months) + 3 months extension

Document information

Deliverable Number	D2.4
Deliverable Title	Dissemination Event with Local Stakeholders
Version	1.0
Dissemination Level	Public
Work package	WP2
Authors	Marios Valanides (RECS)
Contributing partners	FRC, UCY, RECS
Delivery Date	24.05.2024
Planned Delivery Month	M24
Keywords	Dissemination, Communication, Exploitation, Demonstration, Stakeholders

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Version History

No	Description	Author	Organization	Date
1	First draft	Mr Marios Valanides	RECS	22.05.2024
2	Second draft with the addition of Partners' contribution	Mr Marios Valanides	RECS	23.05.2024
3	Review of the document	Dr Pericles Savva Dr Demetris Nicolaides	RECS/FRC	23.05.2024
4	Final version with integration of the reviewers' feedback	Dr Demetris Nicolaides	FRC	24.05.2024

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The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

1. Introduction

Deliverable 2.4 of Work Package 2 (D2.4 – "Dissemination Event with Local Stakeholders") of the BAM project (EXCELLENCE/0421/0137) focuses on disseminating the experimental results achieved in the BAM project. The event targeted local stakeholders, including representatives from engineering consulting firms, cement/concrete/construction/materials companies, academia, governmental organizations, standardization bodies, and other related fields. The aim was to showcase novel materials developed with blast, impact, and fireproof characteristics. The main event highlights are summarised below:

Presentations:

- Consortium members delivered comprehensive presentations explaining the theory behind the developed materials.
- Detailed descriptions of the experimental results were provided.

Experimental Demonstration:

- A live experimental setup was used to demonstrate the fire resistance capabilities of the BAM materials.
- Three different systems were exposed to fire (direct flame exposure) to showcase their fire resistance characteristics.

This report is divided into two sections, supplemented with annexes as described below:

- **Section 1**: Presentations detailing the experimental results.
- **Section 2**: Experimental demonstration highlighting the fire resistance of the materials.
- **Annexes (A-C)**: Includes the event brochure, invitation, presentations and photographic documentation from the event.

GDPR Compliance:

As this is a public deliverable, the detailed list of invitees and participants (names and contact details) is not included to comply with GDPR regulations.

The successful completion of the dissemination event was made possible by the sincere support, effort, and collaboration of all consortium partners. The event is expected to equip local stakeholders with essential information for market penetration of the BAM materials and provide valuable feedback for further product development and business strategy refinement.

2. Objective

On May 21, 2024, a dissemination event was held at the premises of RECS Civil Engineering & Partners LLC to present the methodological approach and experimental results of the "BAM-Blast and Fire Resistant Material" project. Invitations (Figures 1 and 2) were sent to a targeted list of local stakeholders, providing details about the date, venue, a brief description of the BAM project, and an agenda of the presentations.

Following the presentations, an experimental demonstration was conducted to showcase the fire-resistance capabilities of the end products to the attendees.

Figure 1: Invitation of the Dissemination Event (front page).

Figure 2: Invitation of the Dissemination Event (back page).

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3. Presentations

To showcase the methodological aspects, features, and experimental results of the BAM project, the dissemination event was divided into four distinct PowerPoint presentations. Each presentation covered the development and validation of the two new building materials, which were specifically engineered for unique characteristics. These presentations aimed to inform attendees about the challenges faced during development, the experimental procedures followed, and the success in achieving the predetermined goals.

Annex B contains the brochure provided to stakeholders, which includes detailed information about the project's objectives, consortium members, and the overall impact of the BAM project.

3.1 1st Presentation

The first presentation of the dissemination event was conducted by Dr. Demetris Nicolaides and featured an overview of the BAM project (Figure 3). He began by discussing the challenges faced by the construction sector in recent years due to blast, impact, and fire incidents. He then introduced the two novel BAM materials: the Hybrid Laminated Material (HLM) and the Smart Composite Geopolymer Concrete (SCGC), which were designed, developed, and validated to address these issues.

Dr. Nicolaides explained the work behind the mixture design, advantages, and characteristics of these materials, with detailed experimental results to be presented in subsequent presentations. He also shared information about the project's overarching objectives, implementation plan, and consortium, as well as relevant publications arising from the investigation of HLM and SCGC materials. Dr. Nicolaides emphasized how these innovative materials can provide valuable solutions, added value, and new perspectives in the construction industry. The entire presentation is included in Annex C – 1st presentation.

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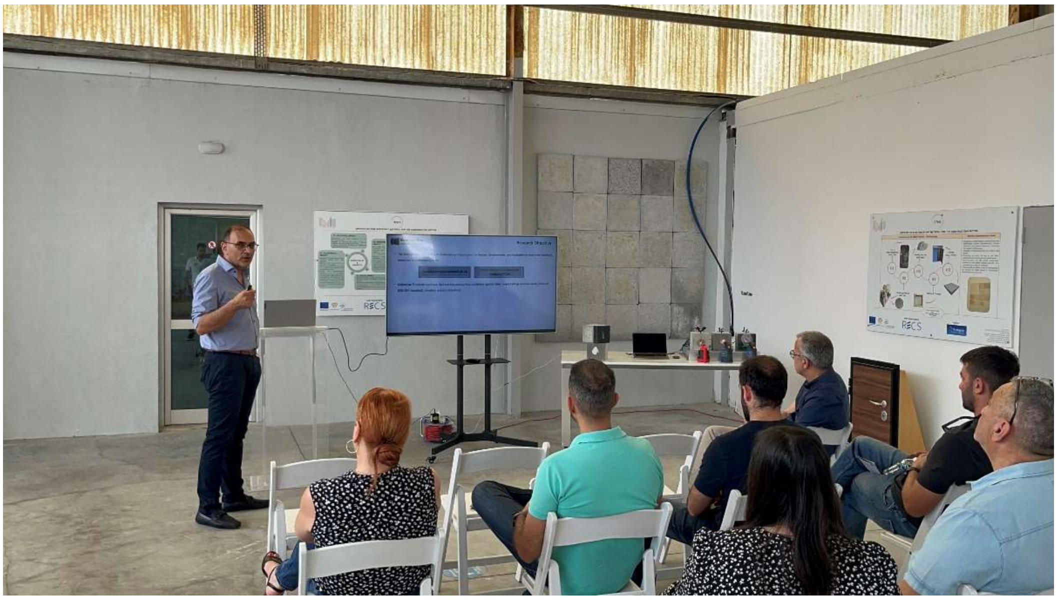
Figure 3: First Presentation delivered by Dr. Demetris Nicolaides.

3.2 2nd Presentation

The second presentation, delivered by Mr. Robert Ponsian, provided an overview of the Fire-Resistant Geopolymer Layer (FRG) of the Hybrid Laminated Material (HLM) (Figure 4). He offered a detailed explanation of the geopolymerization techniques, possibilities, and the important capabilities of the investigated material.

Mr. Ponsian elaborated on how geopolymers enhance thermal properties without compromising structural performance. The presentation included a step-by-step analysis of the design and development of the FRG Layer, from the mixing stage to the curing phase. Through the experimental procedures followed for the final synthesis, attendees gained useful insights into the mechanical performance of FRG when exposed to various high temperatures. This presentation is included in Annex C – 2nd & 4th presentation.

Figure 4: Second Presentation delivered by Mr. Robert Ponsian.

3.3 3rd Presentation

In the third presentation, Mrs. Konstantina Oikonomopoulou provided detailed information about the Ultra High-Performance Fiber Reinforced Concrete (UHPFRC) Layer of the Hybrid Laminated Material (HLM). She outlined the key materials involved in the development and optimization of UHPFRC and informed attendees about the transformation of a previous reference mixture into a new and improved formulation. The presentation emphasized the importance of achieving mechanical performance targets while also providing a composition that minimizes cost and practical challenges in the full-scale, industrial production of the material.

Mrs. Oikonomopoulou addressed the challenges related to curing conditions and described the experimental procedures used to validate UHPFRC. She highlighted the significance of drop-weight impact testing for impact validation and the energy absorption capabilities enabled by the inclusion of steel fibers. Additionally, she provided insights into the bonding between the FRG and UHPFRC layers through their performance evaluation in pull-off testing. The UHPFRC presentation is included in Annex C – 3rd presentation.

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3.4 4th Presentation

Mr. Robert Ponsian delivered the final presentation on the development of the Smart Composite Geopolymer Concrete (SCGC) with fireproof characteristics. He provided a comprehensive overview of the materials incorporated into the SCGC, offering attendees significant insights into the methods used to create the optimal formulation.

Mr. Ponsian specifically discussed the effect (positive and negative) of steel fiber inclusion on compressive strength and its impact on the formation of a stable amorphous aluminosilicate structure. He also emphasized the role of materials such as superplasticizer, local sand, and the addition of silica fume to the alkaline activator in influencing the physical and mechanical properties of the SCGC material. Mr. Ponsian highlighted the importance of defining and exploring these characteristics to improve the final product.

4. Experimental Demonstration

Following the presentations that provided participants with all the necessary information regarding the design, development, and characteristics of the HLM and SCGC materials, a live demonstration of their fire-resistance capabilities was conducted. The focal point of the demonstration included the fireproof performance of three different systems:

1. A standard 15.0 x 15.0 x 15.0 cm concrete cube without a fire-resistant geopolymer layer, serving as the reference system (SCC).
2. A 15.0 x 15.0 x 3.0 cm FRG layer affixed to a concrete cube, defined as HGFRL-CC.
3. A 15.0 x 15.0 x 3.0 cm SCGC layer attached to another concrete cube (SCGL-CC).

To ensure secure adhesion of the geopolymer layers to each concrete system, a quartz adhesion primer was initially applied to both surfaces, followed by a high-temperature sealant silicone. Three blow torches were utilized as the heat source, and temperature recordings and variations were monitored using thermocouples strategically placed as illustrated in Figure 5. The thermocouples were positioned as follows:

- "SCC-A" (1) and "SCC-B" (2) were positioned in the reference system.
- "HGFRL-CC-A" (3) and "HGFRL-CC-B" (4) were positioned in the HGFRL-CC system.
- "SCGL-CC-A" (5) and "SCGL-CC-B" (6) were positioned in the SCGL-CC system.

Checkpoints were selected for fireproof evaluation at 8 cm from the exposed surface (Checkpoint A) and 2 cm from the rear surface.

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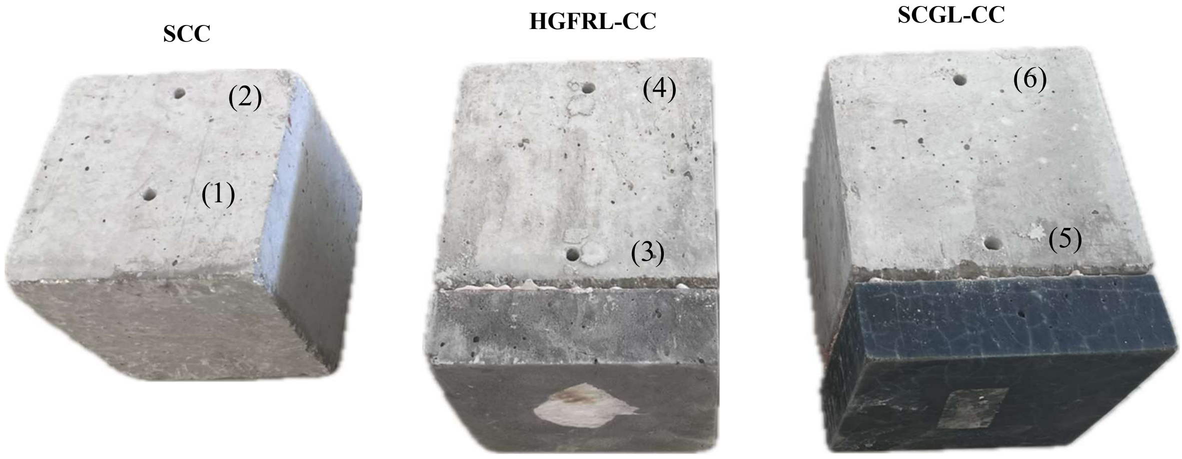

Figure 5: Thermocouples positions within the three designated concrete systems.

Participants were able to observe and understand the effectiveness of the fireproof capabilities of the investigated materials in the three designated configurations, as presented in Figure 6. The temperature variations over time for the different systems are illustrated in Figure 7. Further details regarding mixture compositions, temperature variations, utilized equipment, and experimental results are provided in D4.2 - Validation of Materials in the Laboratory.

Figure 6: Demonstration of fire resistance in the three concrete systems.

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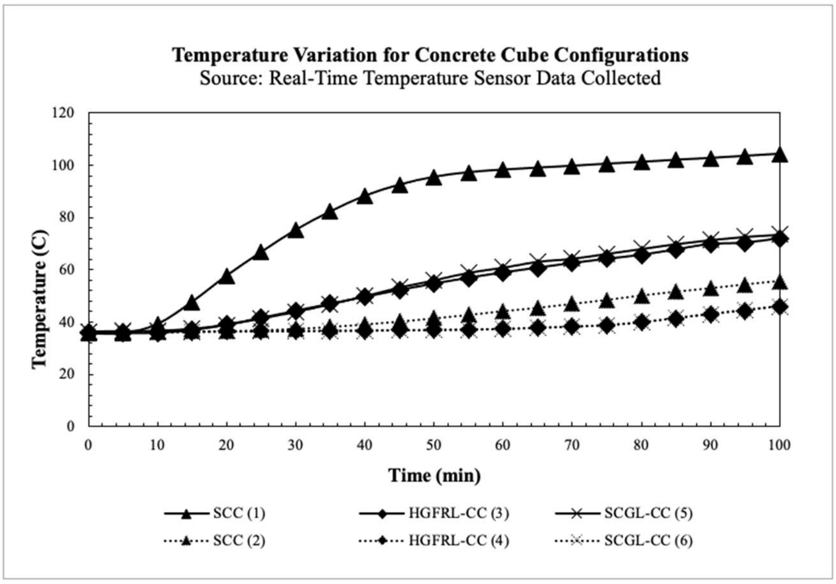

Figure 7: Temperature variations over time for all positioned thermocouples.

5. Conclusions

Deliverable 2.4, titled "Dissemination Event with Local Stakeholders," is part of Work Package 2 of the BAM project (EXCELLENCE/0421/0137). This deliverable documents the dissemination event aimed at promoting the design, development, and performance of a Hybrid Laminated Material (HLM). This innovative material combines a fireproof geopolymer layer with ultra-high-performance fiber-reinforced concrete, offering high blast and impact resistance.

During the first part of the event, attendees were introduced to the objectives, targets, and achievements of the BAM project. The presentations emphasized the efforts behind creating these novel materials and their significance in the construction industry. Participants gained insights into the methodology of geopolymerization techniques and the development of ultra-high-performance concretes, leading to the creation of advanced materials with valuable characteristics.

In the second part of the event, an experimental demonstration of three fireproof concrete systems was conducted. This included one reference system and two systems incorporating the geopolymer fire-resistance materials. These configurations were subjected to high-temperature exposure, with thermocouples strategically positioned within the concrete systems providing real-time data on thermal fluctuations. This demonstration effectively showcased the fireproof capabilities of the geopolymeric materials to the participants.

The dissemination event was deemed successful, providing local stakeholders with compelling evidence of the efficiency and capabilities of the developed materials. It also highlighted the potential for incorporating these products into the construction industry.

Annex A-Brochure

Figures 8 and 9 present the brochure that was distributed to attendees on the day of the dissemination event, providing additional information about the BAM project.

Figure 8: Dissemination Event Brochure – BAM Project (part 1).

Figure 9: Dissemination Event Brochure – BAM Project (part 2).

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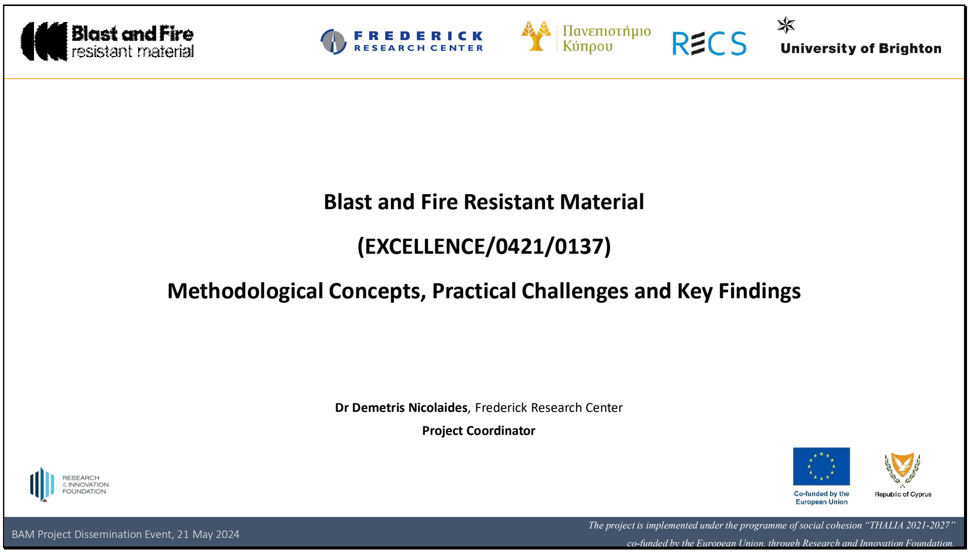
Annex B-Presentations

1st Presentation:

Slide 1



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Slide 3

Problem Definition

Problem definition - 1

- In recent years, a **transformative shift in mentality** has occurred due to a series of large fires which have had far-reaching consequences.
- These devastating incidents have resulted in:
  - **Tragic loss of human lives**
  - **Severe damage to vital structures**
  - **Grave economic implications for regional economies.**

Seventy-two people died after a huge fire engulfed Grenfell Tower, a west London residential tower block, in the early hours of Wednesday, 14 June 2017.

Slide 4

Problem Definition

Problem definition - 2

- Concrete structures face an additional threat: **explosive spalling** when exposed to high temperatures during fire events.
- Numerous **blast incidents** in buildings and critical infrastructure worldwide serve as reminders of the urgent need for enhanced safety measures.

In 2020, Beirut was struck by a catastrophic explosion that inflicted widespread devastation on the city's infrastructure.

In 2011, an explosion wreaked havoc on Cyprus' electricity generating plant, leaving behind a scene of destruction.

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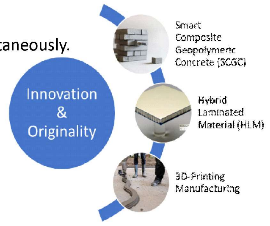
Research Objective

- The BAM project tackles these challenges by focusing on the **design, development, and validation of two novel building materials** at a laboratory scale.

Hybrid Laminated Material (HLM) | **Smart Composite Geopolymer Concrete (SCGC)**

- **Objective:** To create materials that provide appropriate **resistance against blast, impact (drop hammer tests), and fire (ISO-834 standard)**, meeting relevant standards.
- Currently, no existing material possesses both fire and blast resisting properties simultaneously.
- Both materials will be **manufactured with two (2) different methods**:
  - With conventional precast method and
  - With 3D printing manufacturing



Slide 6

Technological Objectives

The Technological Objectives (TO) are the following:

- **TO-1:** Validation of the produced materials at a **lab scale**, in terms of **mechanical** and **durability properties** and also by applying existing **standard tests for fire**.
- **TO-2:** Validation of the produced materials against **blast and impact resistance** with **3 methods**:
  - Achievement of **specific mechanical properties** essential for the blast and impact response of materials
  - By testing materials' specimens against impact loading by conducting **Drop Hammer tests** in the lab. Drop hammer tests will also serve as an **indirect** indicator for the resistance of materials against blast loads and
  - **Finite Element Analysis (FEA)** of the materials' blast resistance.
- **TO-3:** Validate the produced materials in **technoeconomic and cost-benefit analysis** terms by setting a benchmark with the commercially available ones.

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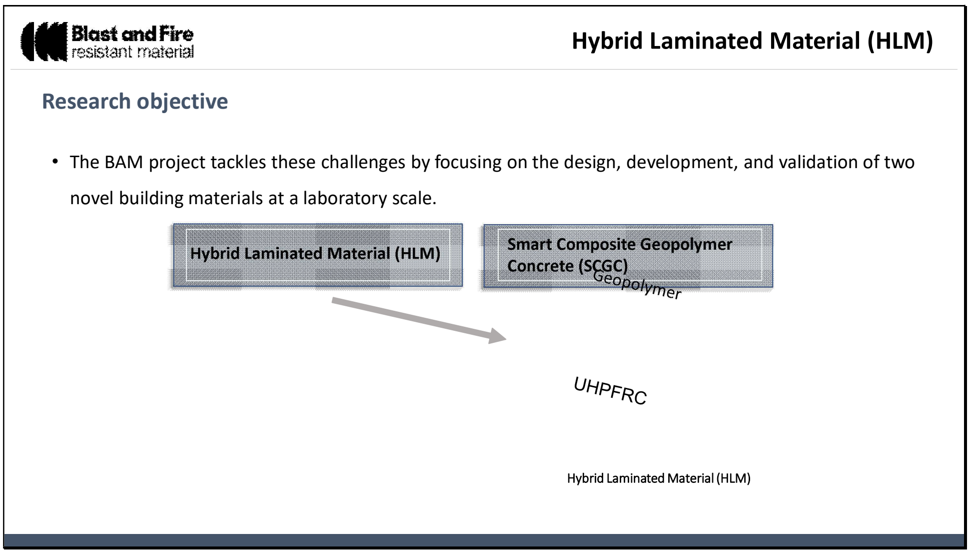

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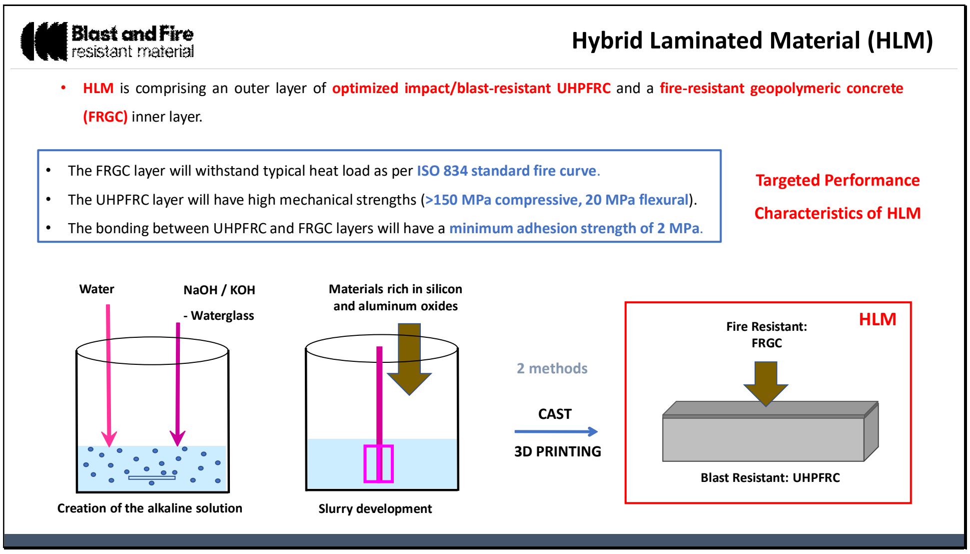

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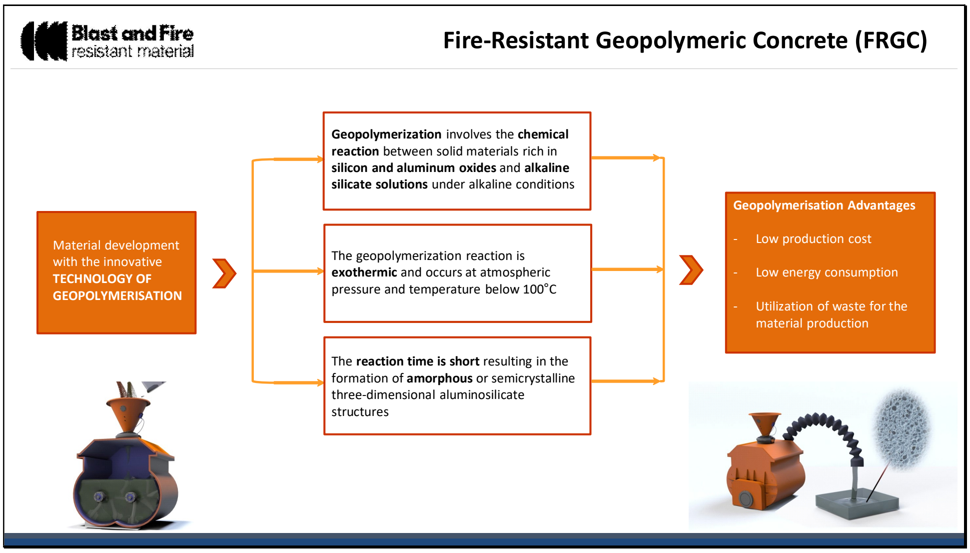

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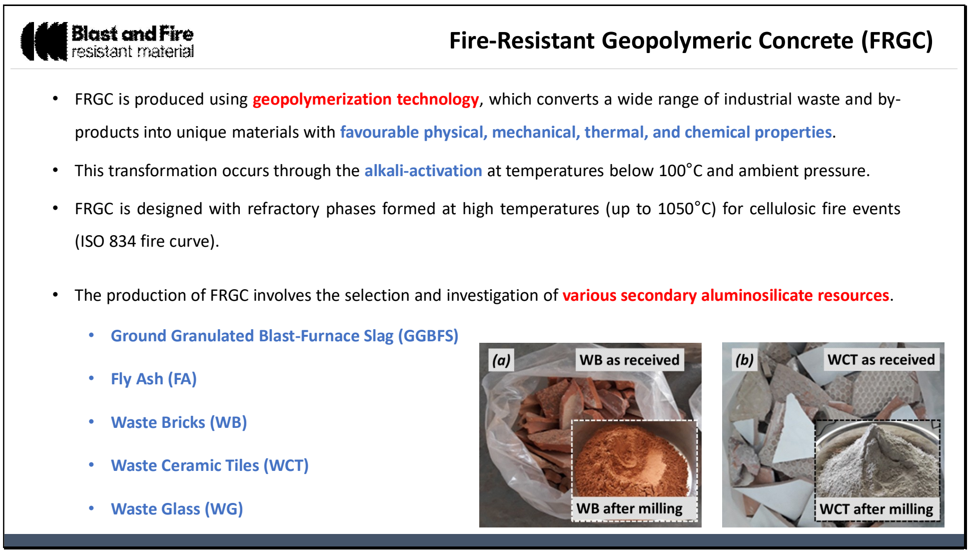

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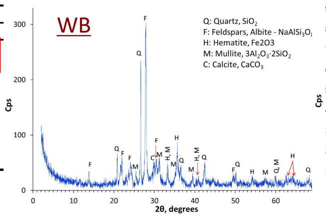
Fire-Resistant Geopolymeric Concrete (FRGC)

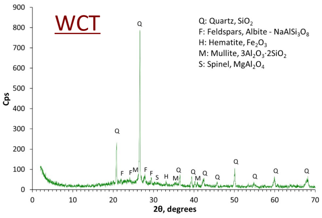
	GGBFS	FA	WB	WCT	WG
	mass, % wt.				
SiO_2	36.9	47.42	53.57	62.4	76.56
Al_2O_3	8.81	19.16	14.33	14.68	10.34
CaO	44.75	16.85	7.71	1.48	
FeO	0.41	7.64	10.19	8.58	0.24
K_2O	0.32	1.67	3.74	3.76	0.92
MgO	7.04	2.68	4.07	3.68	3.96
Na_2O		0.61	0.66	0.98	8.76
TiO_2	0.59	1.25	1.46		

Chemical Analysis performed with X-Ray Fluorescence method (ED-XRF spectrometer SPECTRO XEPOS)

Mineralogical Analysis performed with X-Ray Diffraction (XRD) method



Principally Crystalline – mainly Quartz, Feldspars, Hematite and Mullite – minor Calcite

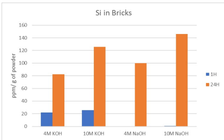


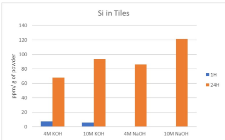
Amorphous Aluminosilicate Phase – Quartz is the main crystalline constituent and Feldspars secondary

Alkaline Activators:

Solutions of NaOH and KOH alkali hydroxides prepared in the lab

Commercially available alkali silicate solutions Na_2SiO_3 (MERCK; molar ratio Na/Si = 0.57) and K_2SiO_3 (MULTIPLASS S.A.; molar ratio K/Si = 0.65), were used for the preparation of the FRGC





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Fire-Resistant Geopolymeric Concrete (FRGC)

(3) Mixing (150 rpm, 5 min) → Homogeneous Paste

(4) Casting → Cubes 50 mm and 100 mm

(5) Curing (30 °C, 7 days)

(6) Demoulding

FRGC
Inorganic Polymers

MOST PROMISING
MIXTURES

Volume Stability, Surface Cracking, Density, Compressive Strength

Thermal Stability

- Muffle Furnace
- Heating Rate: 4.4 °C/min
- Testing Temperatures:
  600 °C, 800 °C, 1050 °C
- Testing Duration: 2 Hours

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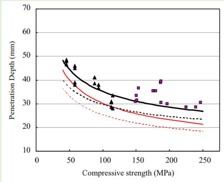
UHPFRC Optimisation for Impact Resistance

Experimental Program

Requirements:

- Zhang et al:



Zhang M, Shim V, Lu G, Chew C (2005) Resistance of high-strength concrete to projectile impact. International Journal of Impact Engineering 31:825-841.

- 150 MPa compressive strength
- 20 MPa flexural strength
- A workable mixture
- Optimised mixture

Reference mixture:

Constituent	Content (kg/m³)
Cement	880
Microsilica	220
Sand 125-250μm	475
Sand 250-500μm	358
Water	172
Superplasticizer	67
Steel fibers 6mm	401
Steel fibers 13mm	80
Water/Binder	0.16

Nicolaides D, Kanellopoulos A, Savva P, Mina A, Petrou M (2013) Mix design and mechanical properties of ultra high performance fibre reinforced cementitious composites (UHPFRCCs), Proceedings of the 1st International RILEM Conference on Rheology and Processing of Construction Materials, Paris, France.

Experimental Program:

a. Microsilica contents

b. Water-binder ratios

c. Curing conditions

d. Fiber type (monofiber steel and hybrid steel & PVA)

e. Volume of fibers

f. Proportions of fibers with different lengths

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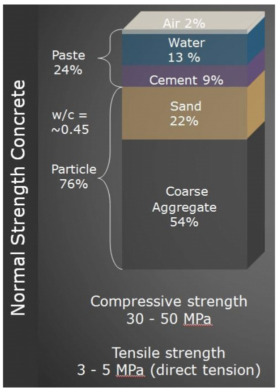
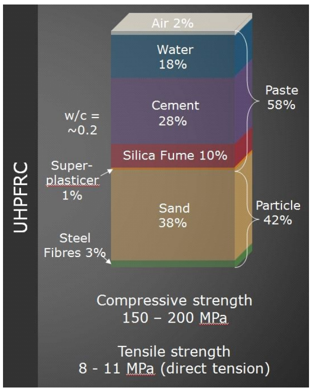
UHPFRC Optimisation for Impact Resistance





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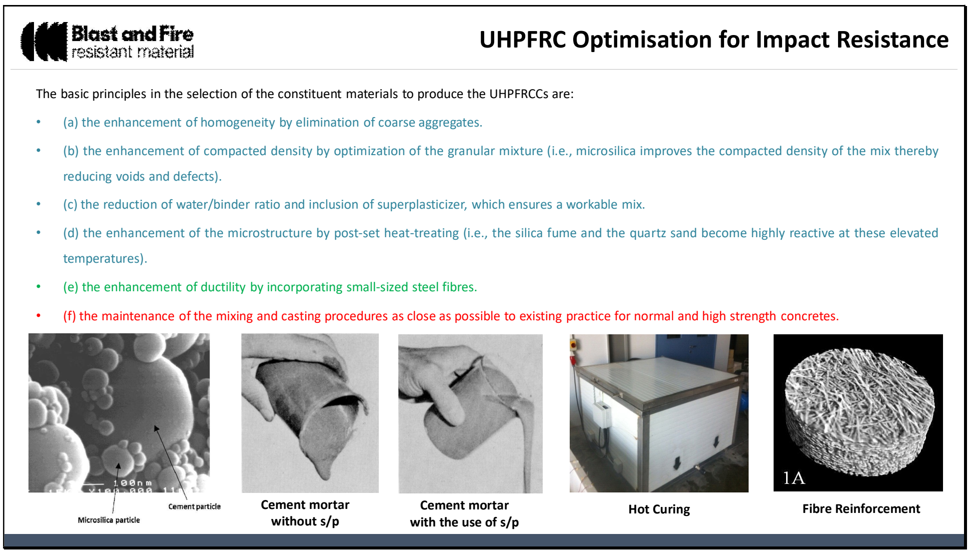

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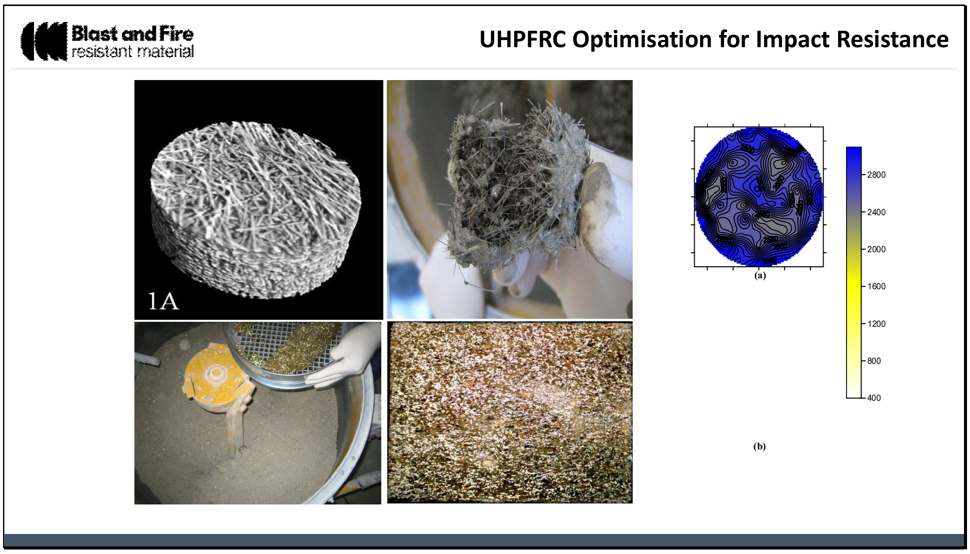

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Blast and Fire resistant material

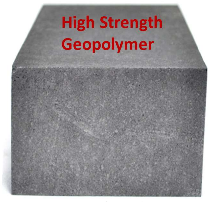
Smart Composite Geopolymeric Concrete (SCGC)

Research objective

- The BAM project tackles these challenges by focusing on the design, development, and validation of two novel building materials at a laboratory scale.

Hybrid Laminated Material (HLM)

Smart Composite Geopolymeric Concrete (SCGC)



Smart Composite Geopolymeric Concrete (SCGC)

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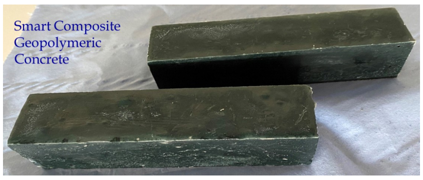
Blast and Fire resistant material

Smart Composite Geopolymeric Concrete (SCGC)

Material	Mix proportions [kg/m^3]			
	PG	SFRGC	PVAFRGC	NSC
Fly ash	388	388	388	–
Slag	310	310	310	–
Silica fume	78	78	78	–
Cement	–	–	–	380
Alkaline activator	93	93	93	–
Water	194	194	194	194
Sand	1052	1052	1052	920
Gravel	–	–	–	800
Steel fibre	–	234	–	–
PVA fibre	–	–	26	–



- Development of an innovative material that **combines fire resistance with impact and blast resistance**.
- Experimental results show that the new material has a **compressive strength exceeding 130 MPa** and a **flexural strength of approximately 9 MPa**. It withstands temperatures **above 1050 °C for two hours**, demonstrating excellent fire resistance.
- This advanced material is produced using **geopolymerization technology at ambient temperature**, significantly reducing its environmental footprint.
- It utilizes **industrial waste**, specifically blast furnace slag, adding to its sustainability.
- **Various fibers are currently tested experimentally** to further enhance the material's flexural strength, impact resistance, and blast resistance.

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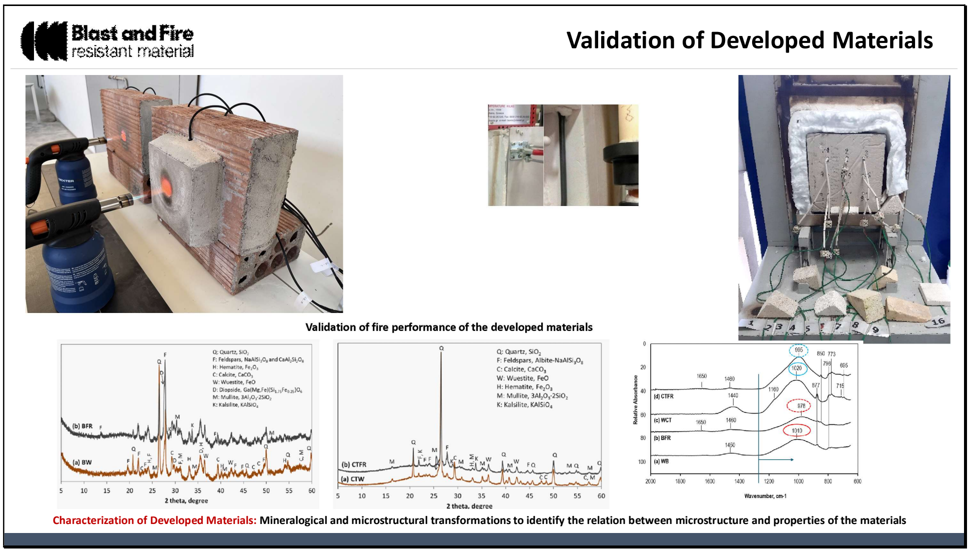

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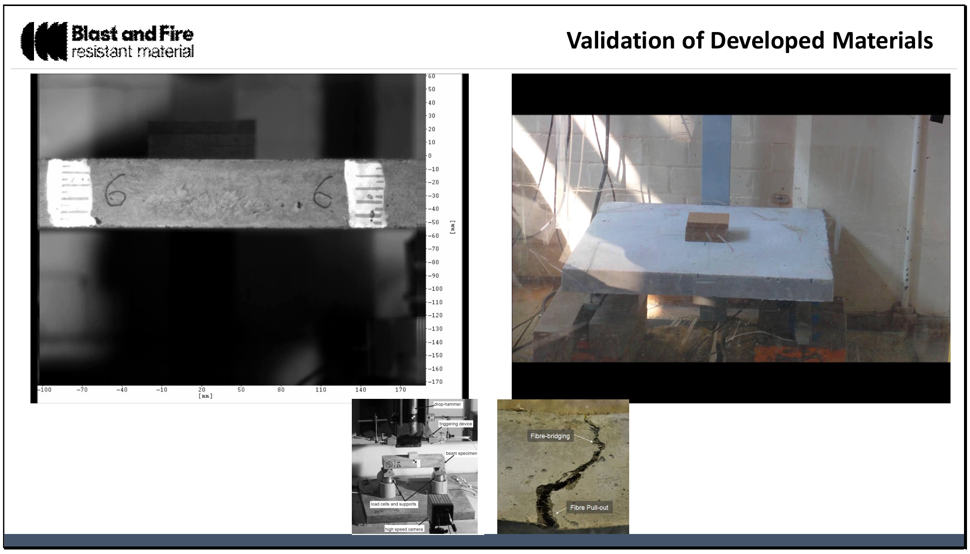

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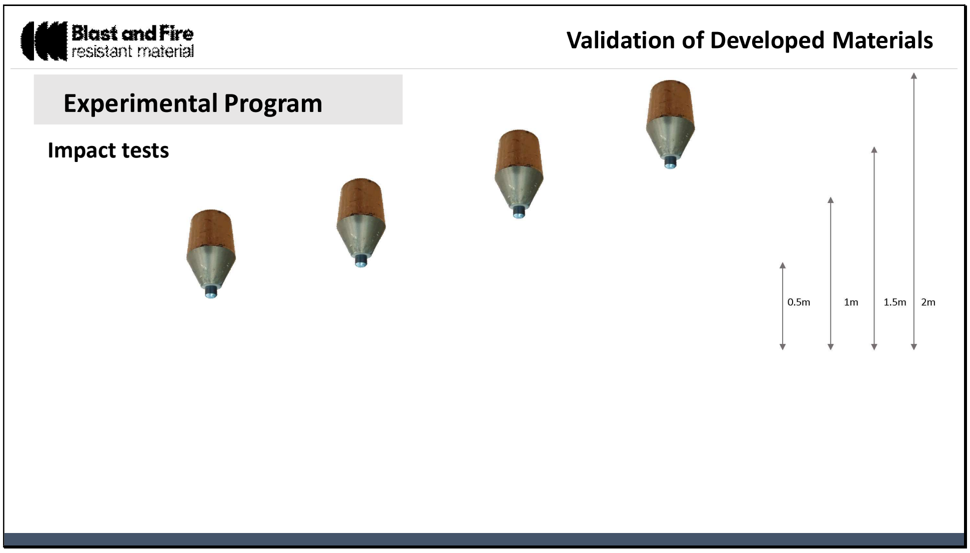

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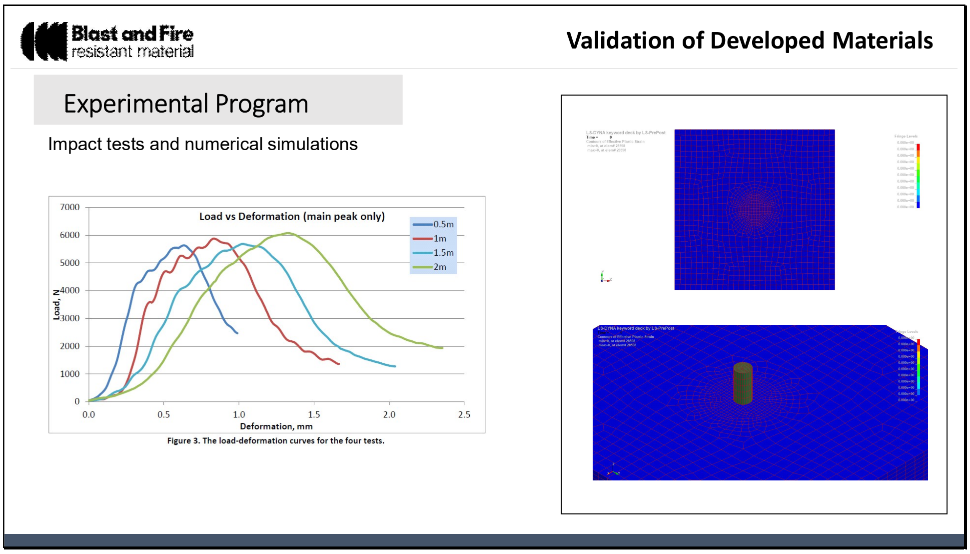

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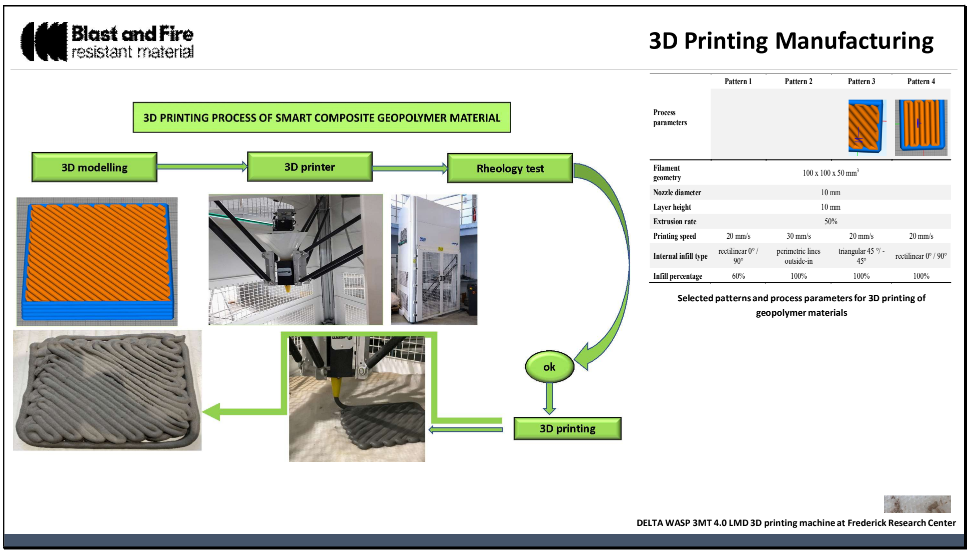

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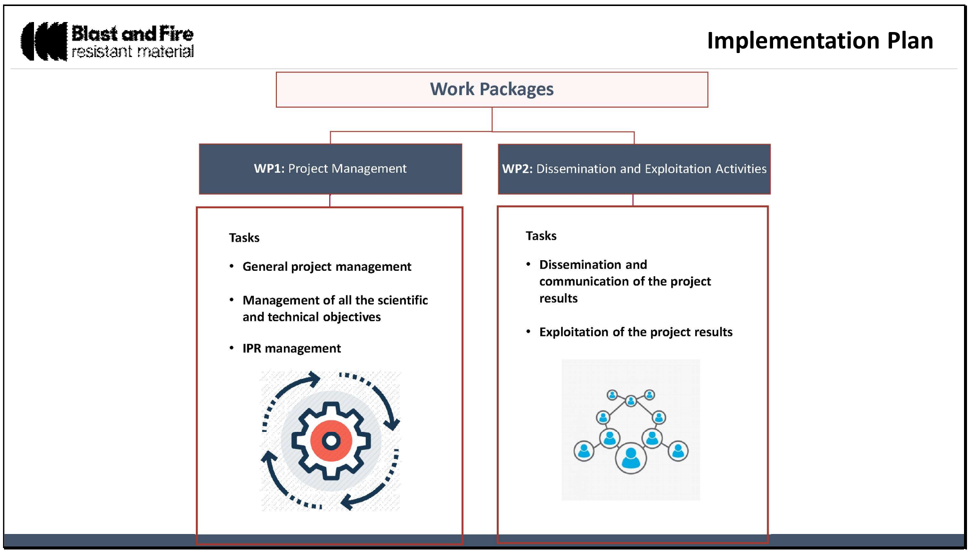

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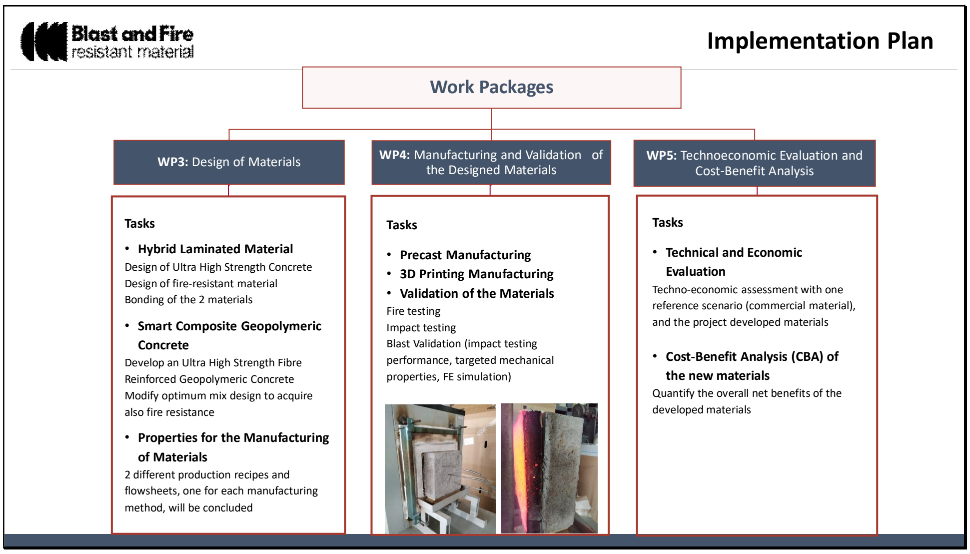

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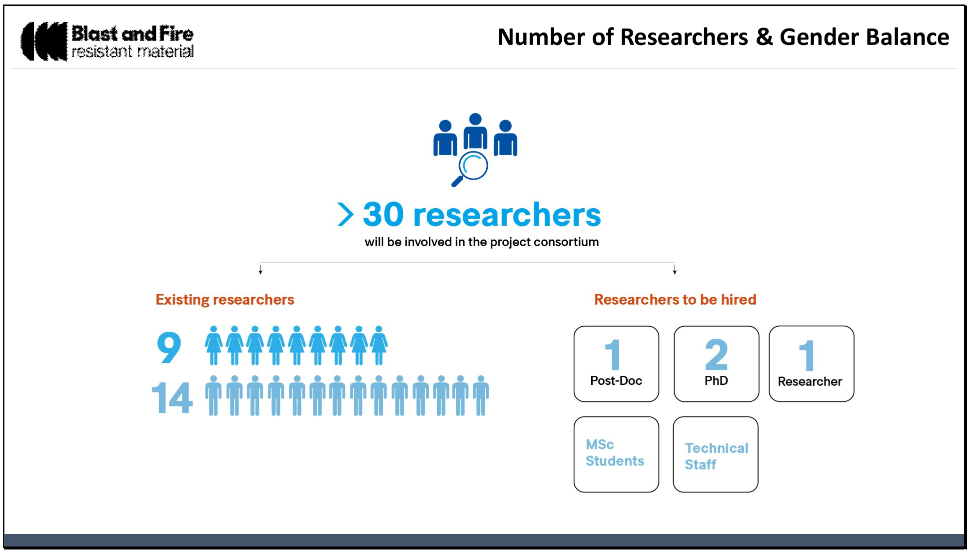

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Relevant Publications and Project's Website

1. Demetriou, D., Polydorou, T., Oikonomopoulou, K., Savva, P., Giannopoulou, I., Robert, P., Tsioulou, O., Lampropoulos, A., Nicolaides, D. and Petrou, M. Optimising Ultra High-Performance Fibre-Reinforced Concrete for Impact Resistance. Proceedings of fib Symposium 2023, Building for the future: Durable, Sustainable, Resilient, Istanbul, Turkey, 05-07 June, 2023.
2. Giannopoulou, I., Ponsian, R., Polydorou, T., Demetriou, D., Tsioulou, O., Lampropoulos, A., Petrou, M. and Nicolaides, D. Novel blast and fire resistant composite materials: design and preliminary results. Proceedings of fib Symposium 2023, Building for the future: Durable, Sustainable, Resilient, Istanbul, Turkey, 05-07 June, 2023.
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5. Giannopoulou, I., Robert, P., Sakkas, K., Petrou, M. and Nicolaides, D. High temperature performance of geopolymers based on construction and demolition waste. Journal of Building Engineering, 72, 2023.
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10. Lampropoulos, A., Nicolaides, D., Paschalis, S. and Tsioulou, O. Experimental and numerical investigation of the size effect of Ultra High-Performance Fibre-Reinforced Concrete (UHPFRC). Materials, 14, 5714, 2021.
11. Nicolaides, D. and Markou, G. Modelling the flexural behaviour of fibre reinforced concrete beams with FEM. Engineering Structures, 99, 2015, pp. 653-665.

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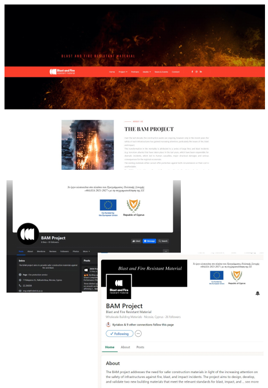

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2nd and 4th Presentation

Slide 1

FREDERICK RESEARCH CENTER · Πανεπιστήμιο Κύπρου · RECS · University of Brighton

Blast and Fire Resistant Material

(EXCELLENCE/0421/0137)

Development of Hybrid Laminated Fire-Resistant Geopolymer

Ponsian M.Robert, Frederick Research Center

PhD Student

RESEARCH & INNOVATION FOUNDATION

Co-funded by the European Union · Republic of Cyprus

BAM Project Dissemination Event, 21 May 2024

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Slide 2

Blast and Fire resistant material

OUTLINE

- INTRODUCTION
- METHODS
- RESULTS
- CONCLUSION

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Slide 3

INTRODUCTION

Geopolymerization technology involves the **chemical reaction** between solid materials rich in **silicon and aluminum oxides** and **alkaline silicate solutions** under alkaline conditions.

Geopolymerization reaction mechanism

- Dissolution of Si and Al to form mobile precursors, **$Si(OH)_4$** and **$Al(OH)^-_4$**
- Partial orientation and internal restructuring to form oligomers Si-O-Si and Si-O-Al
- Poly-condensation of oligomers to a 3-D network
- Hardening to a solid structure

Geopolymerization advantages

- Low production cost
- Low energy consumption
- Utilization of waste for the material production
- GP based materials have excellent early mechanical strength and good fire resistance

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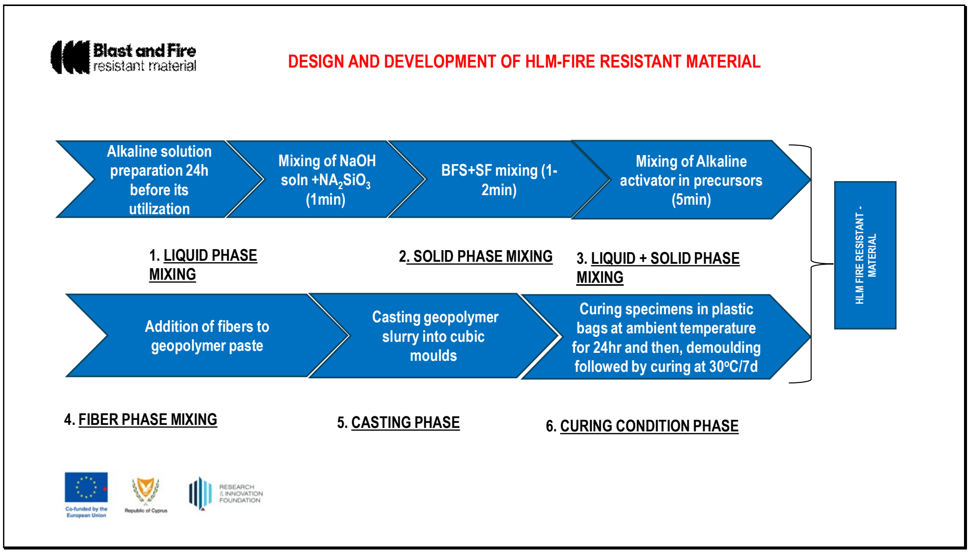

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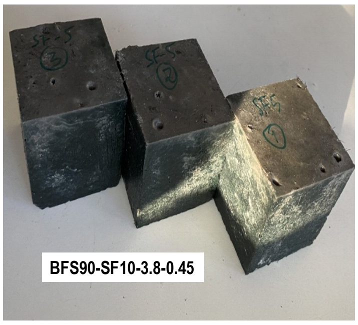
FINDINGS

Fire-resistant geopolymers are materials that are geo-synthetically produced through chemical reaction between precursors and alkaline activators under ambient temperature to form a three-dimensional network.

Table 1. Synthesis condition of HLM-FRG

Precursors		Activators			
BFS-90 (g)	SF-10 (g)	NaOH [7M] ml	$Na_2SiO_3.XH_2O$ ml	S/L g/mL	SS/SH
450	50	41	91	3.8	2.2
450	50	41	91	3.8	2.2
450	50	41	91	3.8	2.2
450	50	41	91	3.8	2.2



Slide 6

THERMAL TREATMENT OF FRG

Procedures

- Nine (12) specimens of FRG were prepared and cured in a plastic bag at ambient temperature for 7 days.
- After curing, three (3) specimens were tested for density and compressive strength. The remaining six (6) specimens were thermally treated in a muffle furnace at 600°C, 800°C, and 1050°C to investigate the fire performance of FRG.
- Three specimens were placed in the muffle furnace and exposed to each predefined elevated temperature at a heating rate of 5°C per minute .
- After reaching the desired temperature, the specimens remained at the peak temperature for 2 hours. Following this, the specimens were left in the furnace to cool for 24 hours

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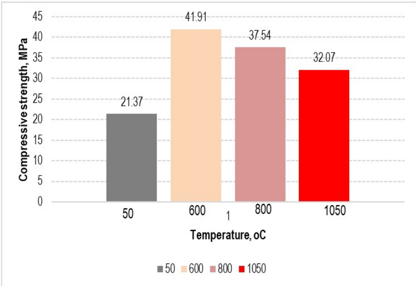
Blast and Fire resistant material



Comments

- The mechanical strength of FRG improved at all elevated temperature, the compressive strength doubled at 600oC and slightly started decreasing at 800oC and 1050oC.
- During macro-observation, no surface cracks were observed on specimens after their exposure to elevated temperatures. Except colour changes from light black to brownish were observed at all temperatures.

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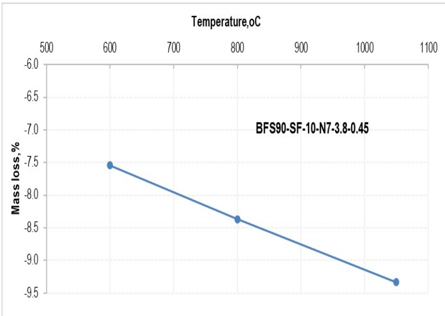
Blast and Fire resistant material

THERMAL TREATMENT OF FRG



Comments

- The FRG lost 8.4% of its total mass after exposure to 600oC and 1050oC due to **hydroxylation** and **dehydration** of geopolymer
- There was improvement of mechanical strength in SCGC after exposure to elevated temperatures. Hence, the geopolymer can withstand high temperature above 1050oC
- The SCGC lost 8% of its total mass after exposed to 600oC and 1050oC

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CONCLUSION-HLM FIRE RESISTANT GEOPOLYMER

- The mechanical strength was of HLM-fire resistant at all elevated temperature, however, the compressive strength doubled at 600oC and slightly decreased at 800oC and 1050oC
- The FRG lost 8.4% of its total mass after exposure to 600oC and 1050oC due to **hydroxylation** and **dehydration** of geopolymer
- There was improvement of mechanical strength in SCGC after exposure to elevated temperatures. Hence, the geopolymer can withstand high temperature above 1050oC

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2. SMART COMPOSITE GEOPOLYMER CONCRETE

Table 2. Synthesis condition of FRG

Precursors BFS-100 (g)	Steel fibers %	Steel fibers (g)	Activators NaOH [7M] ml	Activators $Na_2SiO_3.XH_2O$ ml	S/L g/mL	SS/SH
800	0	0.0	100	150	3.2	1.5
800	1	12.0	100	150	3.2	1.5
800	2	23.0	100	150	3.2	1.5
800	3	35.0	100	150	3.2	1.5
800	5	57.5	100	150	3.2	1.5

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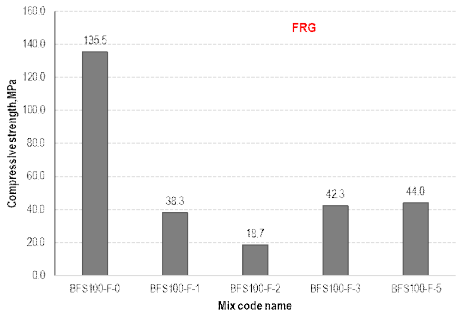
Blast and Fire resistant material

RESULTS OF SCGC



Comments

- The addition of steel fiber in SCGC geopolymer drastically decreased the compressive strength. It seems steel fibers do not participate in the bond formation with Si-O-Si/Si-O-Al to create a stable amorphous aluminosilicate structure.
- The density of SCGC was approximately equal to 2.2g/cm3

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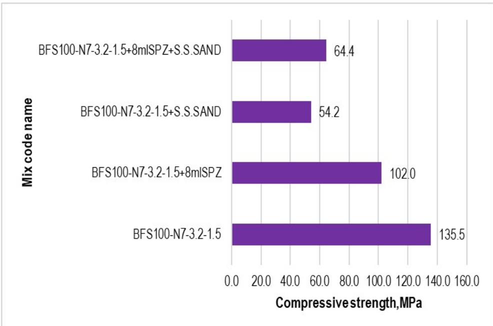
Blast and Fire resistant material

SCGC-RESULTS



Comments

- The addition of superplasticizer in smart composite geopolymer decreased also the compressive strength.
- When the saturated commercial sand used, it also lowered the mechanical strength drastically by 50%

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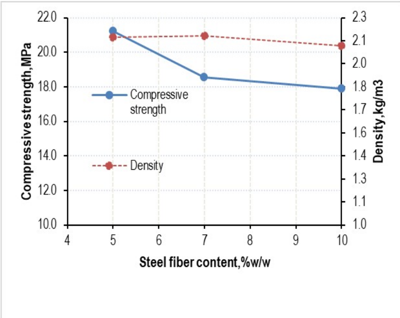
Blast and Fire resistant material

RESULTS OF FRG

1. Addition of SF into the alkaline activator



Comments

- The addition of silica fume in the activator solution decreased the compressive strength of the SCGC by almost one-fourth, the decrease in mechanical strength continued even on increasing the amount of fibers
- The compressive strength of the SCGC increased by more than 100% after adding 5% of steel fibers. Then, compressive strength started decreasing beyond 5% of steel fibers
- The density of the SCGC remained almost the same of about 2.1g/cm3 even on increasing the amount of steel fibers

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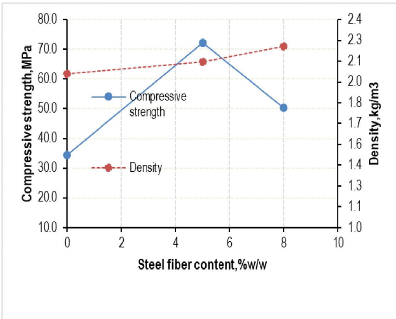
Blast and Fire resistant material

1. Addition of SF into the BFS



Comments

- The compressive strength of the FRG increased by more than 100% after adding 5% of steel fibers. Then, compressive strength started decreasing beyond 5% of steel fibers
- The density of the FRG was 2.1g/cm3

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CONCLUSION

- It is feasible to produce smart composite geopolymer concrete with minimum density of 2.2g/cm3 and compressive strength of 130 MPa.
- The water absorption of the developed SCGC was 0.05
- The addition of steel fibres could not improve the mechanical strength of the SCGM
- The Compressive strength was decreasing as the content of fibers was increasing

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THANK YOU FOR YOUR ATTENTION

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3rd Presentation

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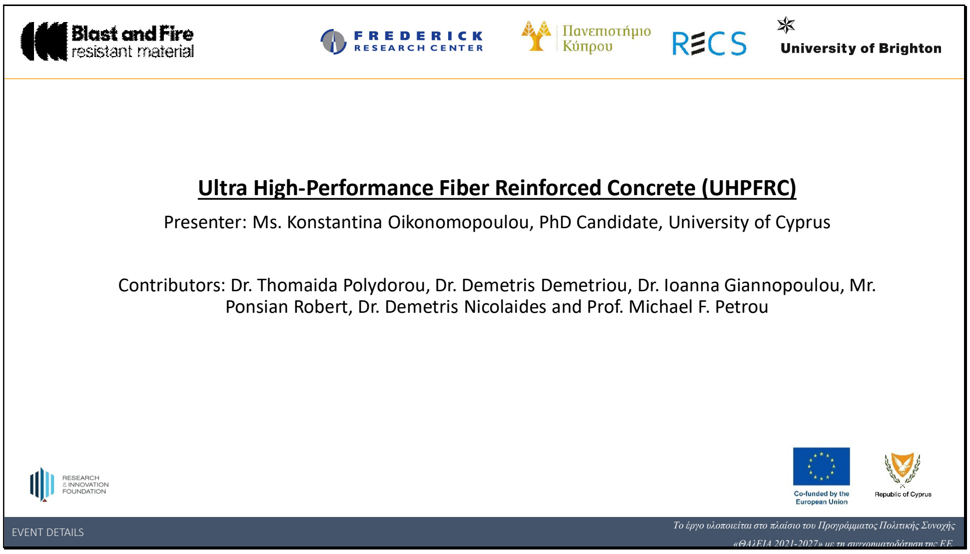

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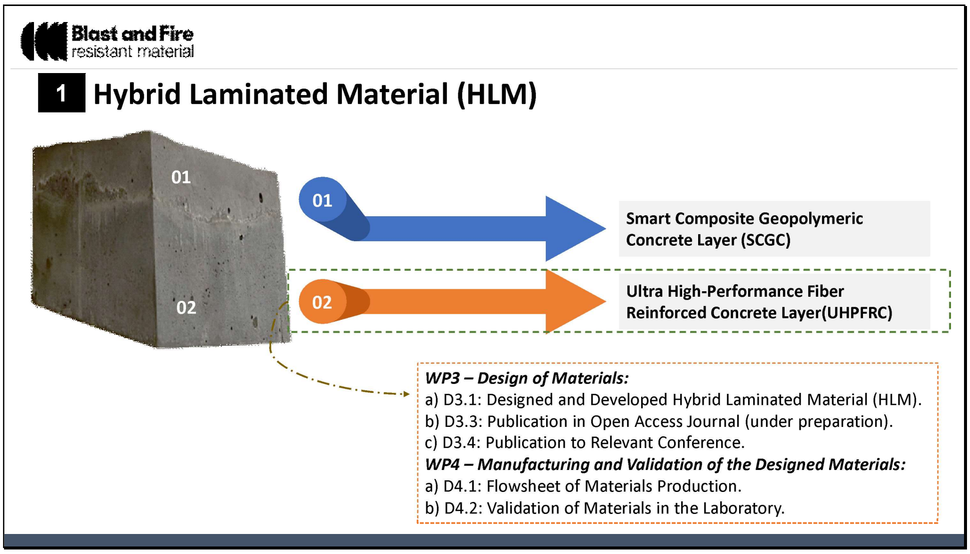

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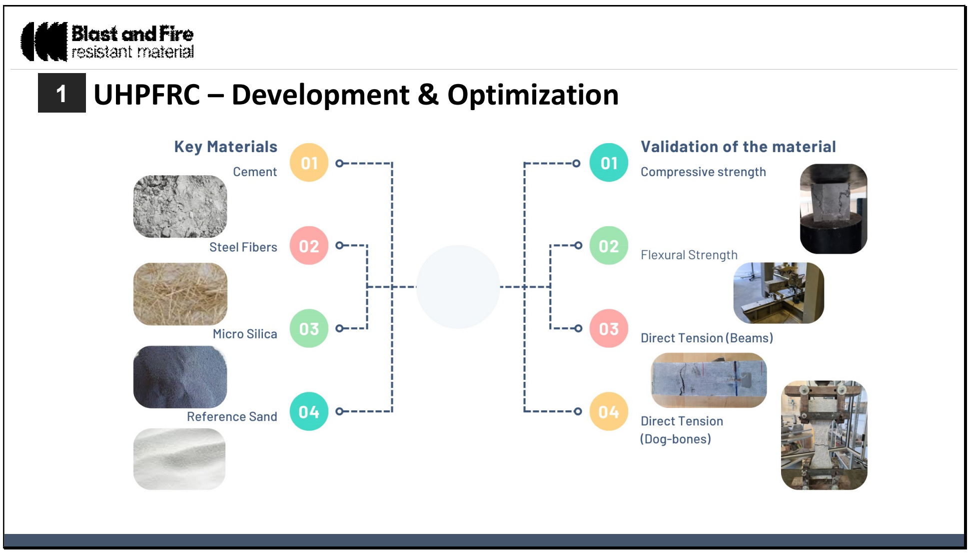

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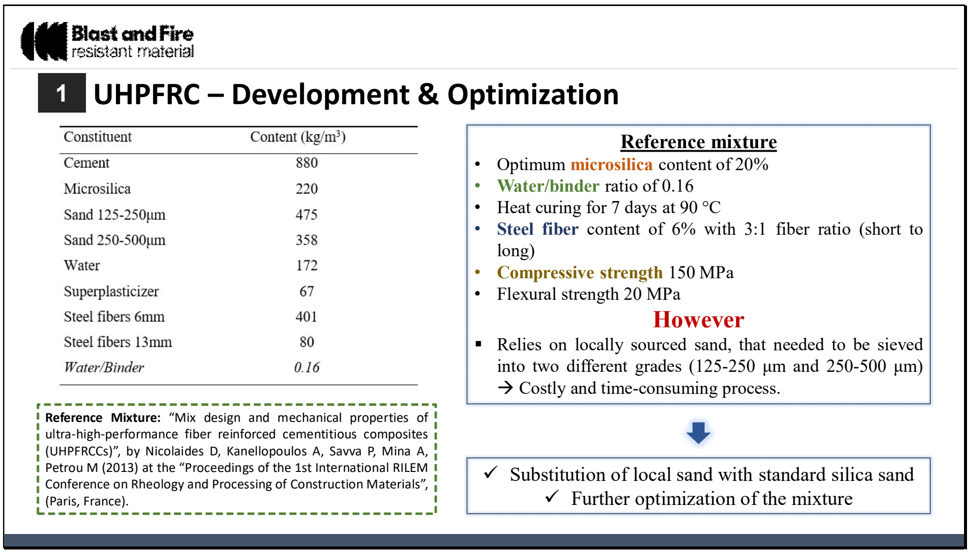

1 UHPFRC – Development & Optimization

Constituent	Content (kg/m^3)
Cement	880
Microsilica	220
Sand 125-250μm	475
Sand 250-500μm	358
Water	172
Superplasticizer	67
Steel fibers 6mm	401
Steel fibers 13mm	80
Water/Binder	*0.16*

Reference Mixture: "Mix design and mechanical properties of ultra-high-performance fiber reinforced cementitious composites (UHPFRCCs)", by Nicolaides D, Kanellopoulos A, Savva P, Mina A, Petrou M (2013) at the "Proceedings of the 1st International RILEM Conference on Rheology and Processing of Construction Materials", (Paris, France).

Reference mixture

- Optimum **microsilica** content of 20%
- **Water/binder** ratio of 0.16
- Heat curing for 7 days at 90 °C
- **Steel fiber** content of 6% with 3:1 fiber ratio (short to long)
- **Compressive strength** 150 MPa
- Flexural strength 20 MPa

However

- Relies on locally sourced sand, that needed to be sieved into two different grades (125-250 μm and 250-500 μm) → Costly and time-consuming process.

✓ Substitution of local sand with standard silica sand
✓ Further optimization of the mixture

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Blast and Fire resistant material

1 UHPFRC - Development & Optimization

Reduction in the steel fibre achieved the required strength goals

- Steel fibre content of **2%** and a **1:1** short to long ratio → Enhanced the 28th day strength **HOWEVER** did not reach the target of 150 MPa.
- **2%** steel fibres, along with **1%** polyvinyl alcohol (PVA) fibre → **Met the goal** of 150 MPa compressive strength

- **Increasing** the fibre content → higher **flexural strength**
- Mixtures containing minimal fibre amounts → **lowest values**
- 2% steel fibres (1:1 ratio) and 1% PVA fibres → highest flexural strength of **22.64 MPa**

Slide 6

Blast and Fire resistant material

1 UHPFRC – Final Mixture Design

Optimized Mixture achieving the benchmark of 150 MPa Compressive and 20 MPa Flexural Strength

Constituent	Steel Fibers 2% & PVA 1%
	Content (kg/m³)
Cement	880
Microsilica	220
Reference Sand	833
Water	172
Superplasticizer	67
Steel fibres 6mm	80
Steel fibres 13mm	80
PVA fibres	13
Water/Binder	*0.16*

Optimized Material Properties

Material Property	Value	Unit
Density	2270	**Kg/m³**
Compressive strength (**MPa**) from Cubes (100 mm × 100 mm × 100 mm)	154.55	**MPa**
Modulus of Elasticity (**GPa**) – from loading cylinders in compression	55.72	**GPa**
Poisson's ratio	0.24	
Tensile strength (**MPa**) from dogbone specimens Cross-sectional area: (50 mm × 25mm)	10.53	**MPa**
Modulus of Elasticity (**GPa**) – from direct tension test on dogbone specimens	50.56	**GPa**
Tensile strength (**MPa**) from prisms Cross-sectional area: (100 mm × 50 mm)	8.9	**MPa**
Modulus of Elasticity (**GPa**) – from direct tension test on prisms	39.5	**GPa**
Flexural strength (**MPa**) from Prismatic Beams (100 mm × 100 mm × 500 mm) (3 point bending test)	29.47	**MPa**

Curing Conditions: The specimens were placed in a water tank where the water temperature was gradually raised from **20** to **90** °C (3rd day) and held at 90 °C for 11 days. On the 13th day, the temperature began to decrease back to **20** °C (14th day), while the specimens remained in water at a temperature of 20 °C until testing.

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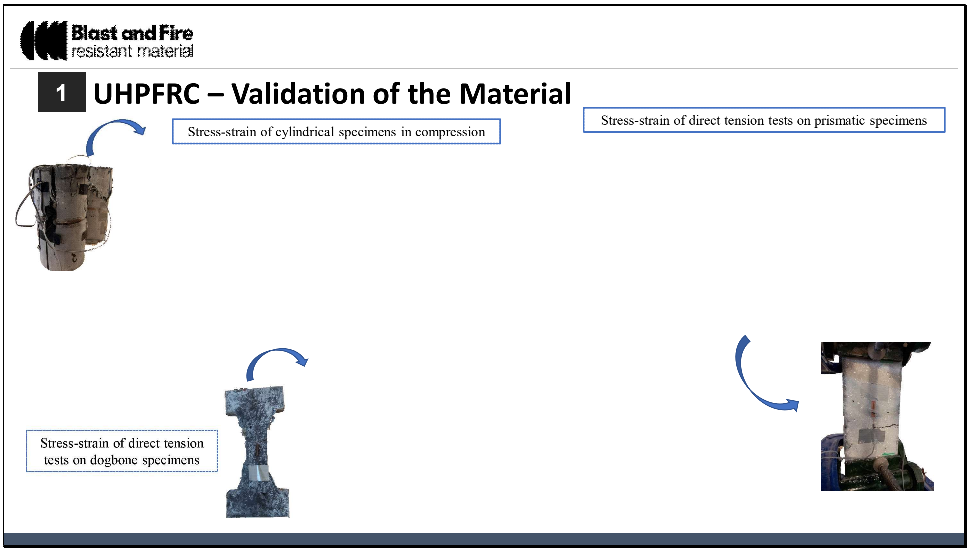

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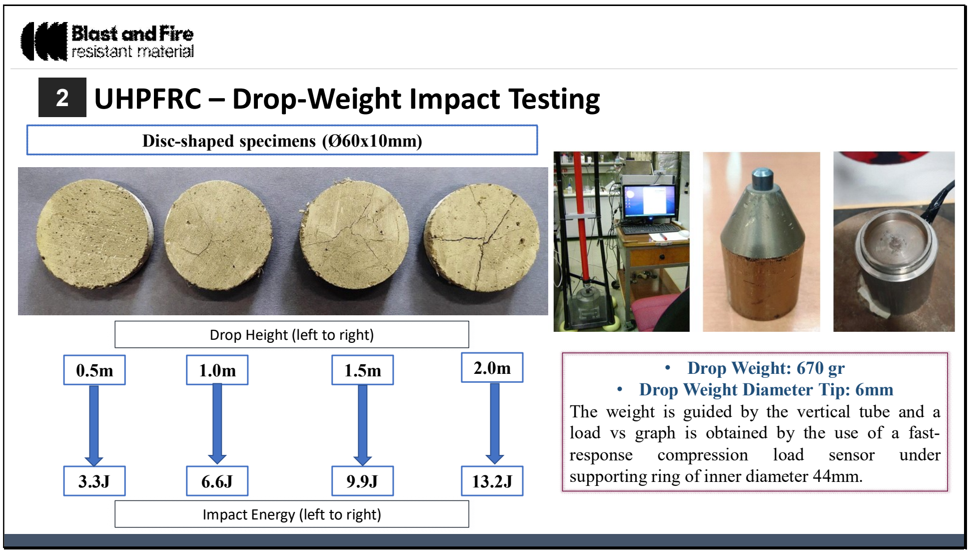

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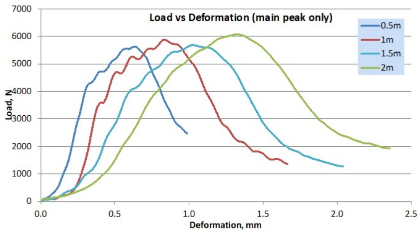
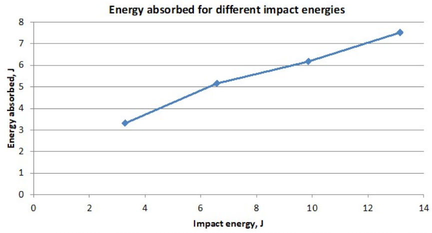
Blast and Fire resistant material

2 UHPFRC – Drop-Weight Impact Testing





✓ Main **peak** at 0.5-1.3mm → 6000N

Drop Height	0.5m	1.0m	1.5m	2.0m
Impact Energy (J)	3.3	6.6	9.9	13.2
Energy absorbed (peak area) (J)	3.3	5.2	6.2	7.5
Ratio energy absorbed (%)	100	78	63	57

- Specimens absorb substantial amounts of drop weight impact ranging from 100% (0.5m) to 57% (2.0m)
- Increased impact energy → increases fracturing
- Energy absorption is enabled by the steel fibres and by the fibres pulling out from the matrix due to frictional energy dissipation.

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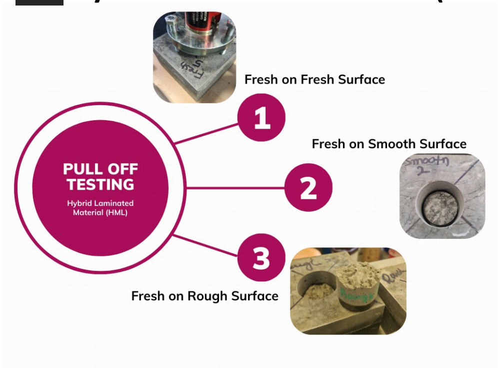
Blast and Fire resistant material

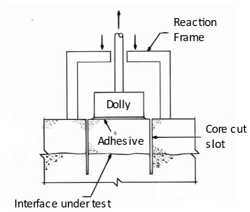
3 Hybrid Laminated Material (HLM) – Pull Off Testing



Pull Off Testing on different setting phases

EN 1542:2000

- Tensile bond strength of repair products and systems applied to concrete substrates.
- Direct dolly pull-off using a dolly fixed to the surface of the compact geopolymer materials.
- Test area → coring through the surface



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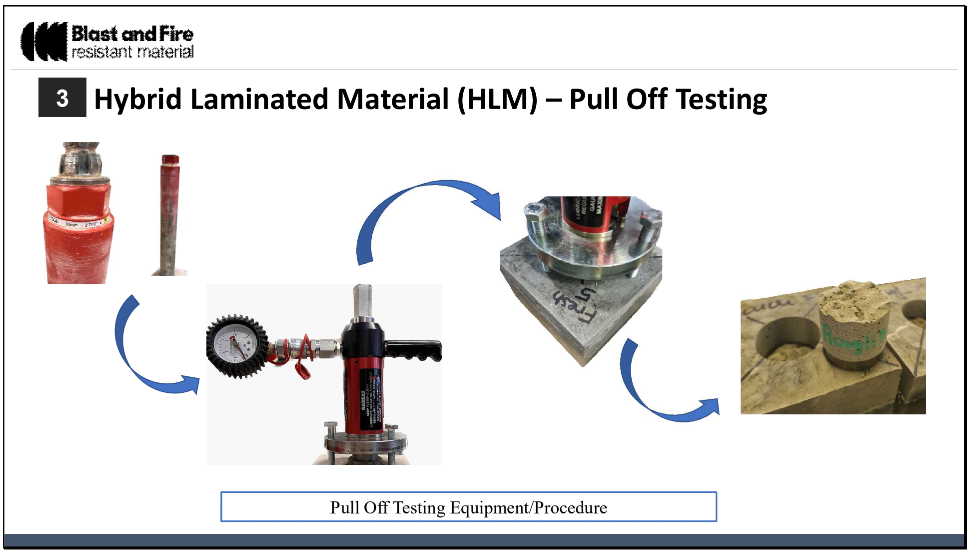

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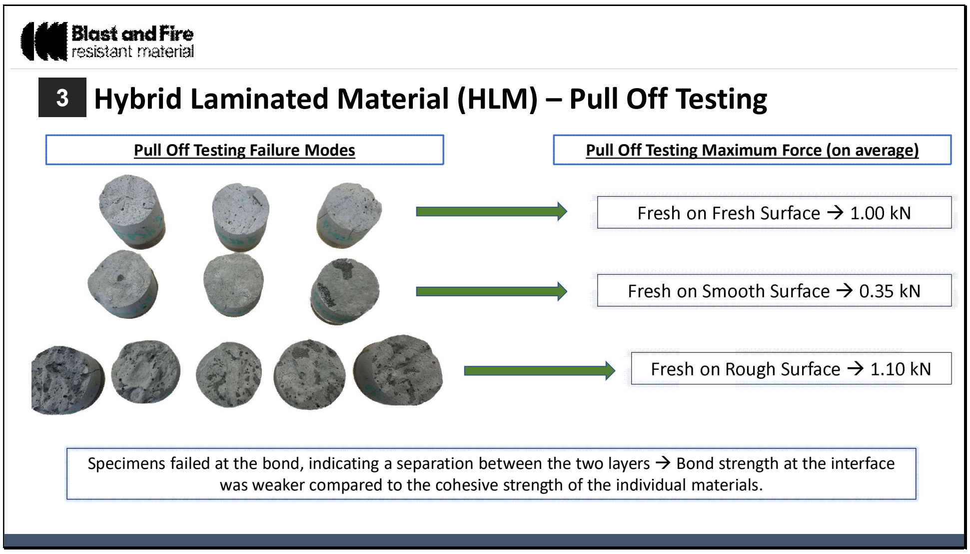

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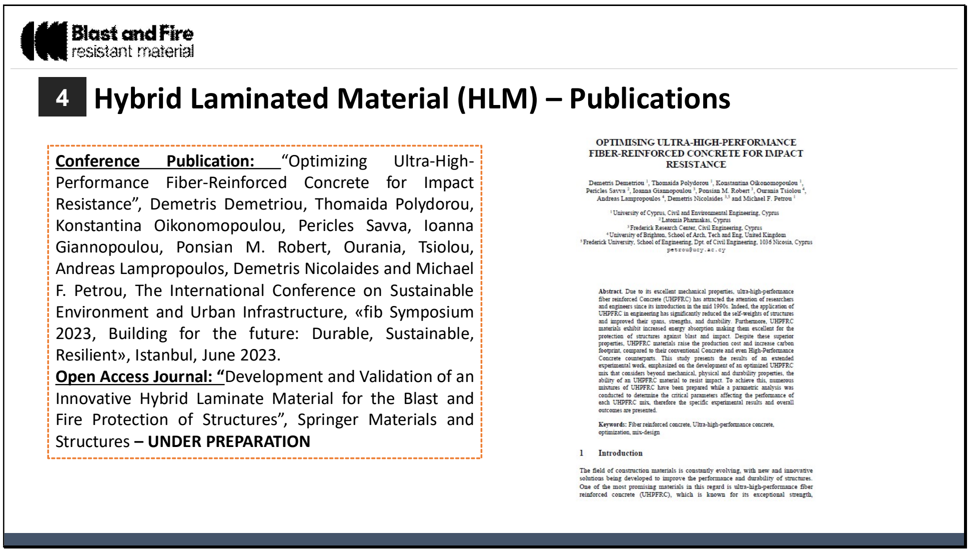
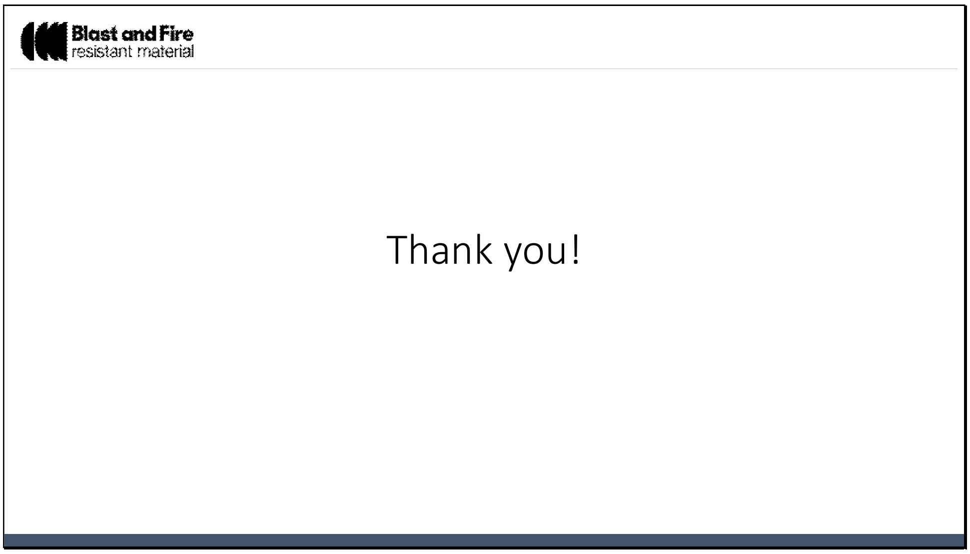
Slide 13



Slide 14



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Annex C-Event Photos

Figure 10:Preparations before the dissemination event.

Figure 11: Setup for the presentations and the fire demonstration.

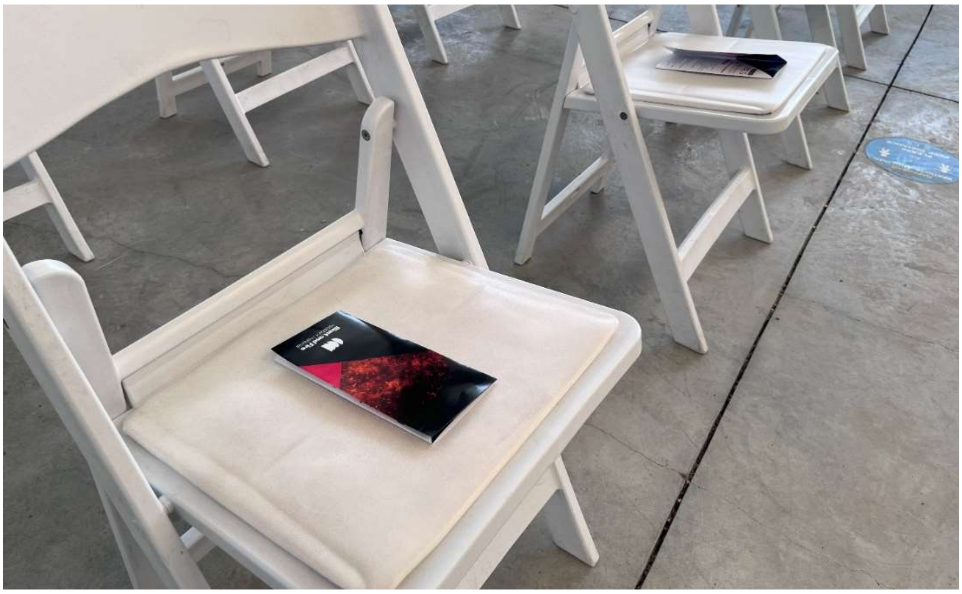

Figure 12: Brochure distributed to the participants.

Figure 13: Presentation delivered by Dr. Nicolaides.

Acknowledgements

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

Το έργο υλοποιείται στο πλαίσιο του Προγράμματος Πολιτικής Συνοχής «ΘΑλΕΙΑ 2021-2027» με τη συγχρηματοδότηση της ΕΕ, μέσω του Ιδρύματος Έρευνας και Καινοτομίας.