Optimising Ultra-High-Performance Fiber-Reinforced Concrete for Impact Resistance

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Abstract. Due to its excellent mechanical properties, ultra-high-performance fiber reinforced Concrete (UHPFRC) has attracted the attention of researchers and engineers since its introduction in the mid 1990s. Indeed, the application of UHPFRC in engineering has significantly reduced the self-weights of structures and improved their spans, strengths, and durability. Furthermore, UHPFRC materials exhibit increased energy absorption making them excellent for the protection of structures against blast and impact. Despite these superior properties, UHPFRC materials raise the production cost and increase carbon footprint, compared to their conventional Concrete and even High-Performance Concrete counterparts. This study presents the results of an extended experimental work, emphasized on the development of an optimized UHPFRC mix that considers beyond mechanical, physical and durability properties, the ability of an UHPFRC material to resist impact. To achieve this, numerous mixtures of UHPFRC have been prepared while a parametric analysis was conducted to determine the critical parameters affecting the performance of each UHPFRC mix, therefore the specific experimental results and overall outcomes are presented.

Keywords: Fiber reinforced concrete · Ultra-high-performance concrete · optimization · mix-design

1 Introduction

The field of construction materials is constantly evolving, with new and innovative solutions being developed to improve the performance and durability of structures. One of the most promising materials in this regard is ultra-high-performance fiber reinforced concrete (UHPFRC), which is known for its exceptional strength, durability, and resistance to impact and blast [1–5]. However, one of the major challenges in the production

A. Ilki et al. (Eds.): *fib* Symposium 2023, LNCE 349, pp. 967–976, 2023.
https://doi.org/10.1007/978-3-031-32519-9_96

of UHPFRC remains the synchronous optimization of the various input parameters for achieving the best properties at the lowest cost and environmental impact.

Indeed, research in recent years has focused on ways to produce UHPFRC while simultaneously reducing its carbon footprint and material costs. Approaches like decreasing the amount of cement by utilizing large quantities of supplementary cementitious materials [6–8], replacing fine standard sand with locally available sand [4], using hybrid fiber systems [9, 10], which can include a combination of steel, polypropylene and polyvinyl alcohol (PVA) fibers among other, and replacing heat with standard curing to reduce energy consumption [11] have been investigated with great reported success. Most recently, research has also focused on the orientation of fibers in UHPFRC as a way of improving the mechanical properties of UHPFRC [12, 13], ultimately enhancing its blast and impact resistance.

Given the various approaches that have been proposed to improve the production of a more economic and environmentally sustainable UHPFRC, it is important to understand the specific effect of the constituting elements on the material properties and performance. Therefore, this paper embarks on an extended experimental program to investigate the combined action of input parameters on UHPFRC performance and establish guidelines to produce an optimized mixture that achieves impact and blast resistance. Specifically, the study is set to examine the effects of microsilica contents, water-binder ratios, curing conditions, fiber type (monofiber steel and hybrid steel & PVA), volume as well as different proportions of fibers with different lengths on the mechanical properties of UHPFRC. The aim is to understand the fundamental mechanisms of these input parameters on the behavior of UHPFRC and provide valuable insights that can be used to improve the production and performance of UHPFRC in construction applications.

2 Materials and Methods

2.1 Materials

The following materials were used in the preparation of all the specimens investigated in this study, namely: (1) ordinary portland Cement CEMI of strength category 52.5N, (2) non-densified microsilica (MS97U), (3) polycarboxylate polymer based superplasticizer in conformity with EN 934-1:2008 and EN 934-2:2009 + A1:2012, (4) calcareous sand with gradings 125–250 μm and 250–500 μm, (5) standard sand in accordance with ISO 9001:2008, ISO 14001:2004, (6) 6 mm and 13 mm brass coated steel fibers of 0.16 mm diameter, (7) Polyvinyl alcohol (PVA) monofilament fibers and (8) water.

For this investigation, the UHPFRC mixture presented by [14] was used as the reference mixture. The mixing quantities of the reference mixture are presented in Table 1.

Table 1. Reference UHPFRC mixture in accordance with [14]

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

2.2 Methods

Mixing, Casting, and Curing. This study adopts the mixing sequence presented in [14] which as a first step requires all dry constituents (cement, sand, microsilica) placed into the mixer and mixed sequentially for 2–3 min. Post placement of the final dry ingredient, steel fibers are added into the mixture. Short 6 mm fibers are added first at several intervals of the mixing sequence to ensure appropriate distribution of the fibers in the mix. A similar process is adopted for the addition of the long 13 mm steel fibers. It is noted that to facilitate the dispersion of the fibers and minimize the effect of fibers adhering to each other, a vibrating (manually operated) sieve was utilized. In the case of mixtures containing PVA fibers, their incorporation into the mixture always succeeded the addition of both denominations of steel fibers. Finally, for the addition of the wet ingredients, superplasticizer was mixed into the water and poured into the dry mix in four increments. At each increment, the wet mixture was mixed for 2–3 min to ensure a densely packed microstructure.

After mixing, specimens were cast in accordance with the European Standards EN 12390-2:2009 and EN 13670:2009 in standard cubic (100 x 100 x 100 mm), long prismatic (100 x 100 x 500 mm), short prismatic (40 x 40 x 160 mm) and cylindrical (D = 150, H = 300 mm) molds. The specimens were water cured at different temperatures (20 °C, 40 °C, 65 °C and 90 °C) for 7 or 11 days (depending on the curing scheme selected) and remained in the curing tank at ambient water temperature (at 20 °C) until testing.

The testing procedures for the derivation of results included an investigation of the workability of each mixture using a flow table and the procedures outlined in EN 1015-3-1999. The compressive, tensile, flexural strength and moduli of elasticity were determined using the procedures outlined respectively in EN 12390-3, EN 12390-6, EN 12390-5, ASTM C469/C469M-10. Accordingly, the compressive strength was evaluated on 6 cubes at various ages for each mixture. The flexural strength of each mixture was examined using 5 long prisms to optimize the steel fiber content, while 3 short prisms were utilized to optimize the hybrid steel and PVA content. A single cylinder was used to test the tensile strength of each mixture. The modulus of elasticity was measured using 5 long prisms and a single cylinder.

Experimental Program. The experimental program consists of a comprehensive series of optimization attempts aimed at identifying the optimal mixture through the investigation of variations of the input parameters of the reference mixture. The sequence of optimization is structured in a systematic and methodical manner, starting with the examination of the effect of various microsilica contents (at 5%, 10%, 15%, 20% and 25%) on workability and 10-day compressive strength. This is followed by the investigation of implementing various W/B contents on the 28-day compressive strength at ambient and elevated 90 °C water temperatures at 7 and 11 days of heat curing. The experimental program continues with the examination of water curing temperatures (40 °C, 65 °C and 90 °C) and duration on the 28-day compressive strength of the microsilica and W/B optimized mixture. The program also includes the investigation of different steel fiber contents on the 28-day specific fracture energy, compressive, flexural, and tensile strength, workability as well as modulus of elasticity. Additionally, the program includes the examination of the effect of different denominations, namely 3:1, 5:1 and 1:1 short 6 mm to long 13 mm steel fibers on the 28-day compressive and flexural strength, and modulus of elasticity. Lastly, the combination of steel and PVA fibers on the 14-day and 28-day compressive strength and 14-day flexural strength was researched.

3 Results and Discussion

This section presents the results of the experimental study on the development of an optimised UHPFRC mixture.

3.1 Curing Temperatures and Duration, W/B Ratio and Microsilica Content

This study aimed to determine the water curing temperature and duration of curing that most effectively optimize the hydration process of cement, resulting in a denser microstructure and stronger bonds within the matrix. To accomplish this, specimens of the reference mixture (as shown in Table 1) were water cured at various temperatures: 40 °C, 65 °C, and 90 °C and a duration of 7 and 11 days respectively. With reference to Fig. 1a, it is evident that the specimens subjected to a water curing temperature of 90 °C had the highest 28-day compressive strength at both 7 and 11 days of curing. Additionally, it is evident that water curing the specimens for 11 days at 90 °C achieved a 7% increase in compressive strength over the specimens cured at the same temperature for 7 days. Therefore, a 90 °C water curing temperature can be arguably considered as an ideal condition for the cement hydration process to occur in UHPFRC specimens, while a 7-day water curing duration at 90 °C can be considered a good balance between strength development and economic/environmental viability of the material.

In the next phase, the water content in the reference mixture of Table 1 was adjusted to achieve a W/B ratio between 0.16 and 0.24 in increments of 0.02. As seen in Fig. 1b, a decreasing trend in 28-day compressive strength was observed as the W/B ratio increased.

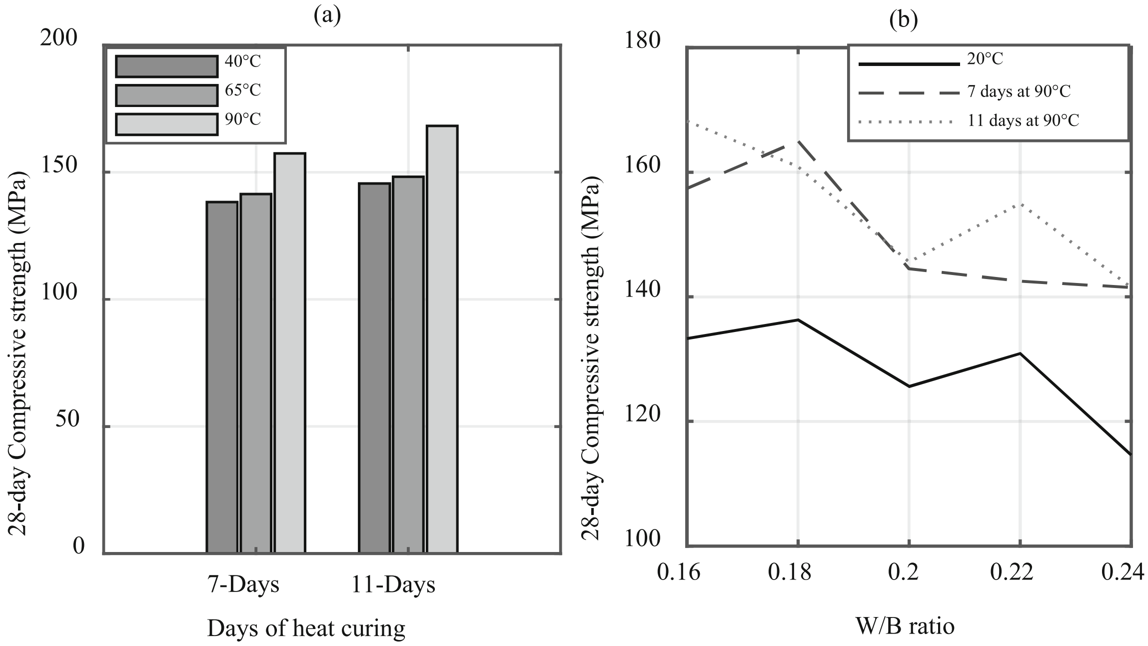

Fig. 1. 28-day compressive strength at (a) different post-set heat treatment temperatures for the 0.16 W/B reference mixture, and (b) varied W/B ratios and water curing durations at 90 °C

Additionally, an examination of the effect of water curing duration at elevated temperatures (90 °C) revealed that specimens that received either 7 days or 11 days of water curing at elevated temperatures had higher compressive strength than those cured conventionally at 20 °C. Given the similarity in compressive strength results obtained from 7 and 11 days of heat curing, it is reasonable to propose a heat treatment duration of 7 days and a W/B ratio of 0.16.

An investigation into the effects of the microsilica content on the compressive strength and workability of the reference mixture (as shown in Table 1) reveals that both properties improved as the percentage of microsilica increased (as seen in Fig. 2). However, it can be noted that incorporating more than 20% microsilica did not have a significant impact on strength possibly owing to the inability of microsilica to appropriately react at low W/B ratios (0.16). In fact, with reference to the same figure, a 7% increase in compressive strength is achieved by increasing microsilica from 15% to 20%, while only a small percentage (0.7%) increase is attained after increasing microsilica contents from 20%–25%. At the same time, the increased workability attained by the 20% microsilica mixture was considered important in the casting of the specimens. For these reasons, 20% microsilica was deemed an optimal input parameter.

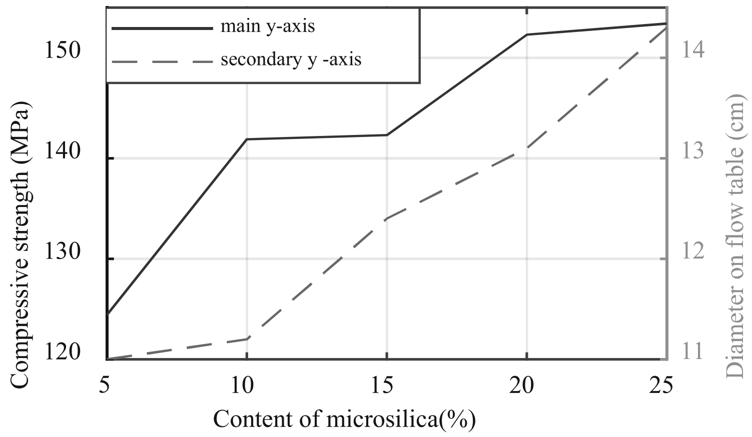

Fig. 2. 10-day compressive strength (left y-axis) and workability (right y-axis) results at varied microsilica contents

3.2 Fiber Content and Size Distribution

The effect of various steel fiber contents (2% to 10% per volume in 2% increments) on the specific fracture energy, compressive strength, flexural strength, tensile strength, modulus of elasticity, and workability of UHPFRC was investigated. A nominal 3:1 short 6 mm to long 13mm steel fiber content was used in the study.

The results presented in Fig. 3, indicate that the influence of steel fibers on the mechanical properties of mixtures containing low steel fiber contents (e.g., 2–4%) is not significant. This could be attributed to the sparseness of fibers within the specimen, which may not be sufficient to impart a significant improvement in the mechanical properties. On the other hand, mixtures containing higher steel fiber contents (>6%) exhibited a significant increase in all the investigated mechanical properties (as evident by the positive steep gradient of the lines in Fig. 3). Specifically, an increase of approximately 39% in compressive strength, 13% in flexural strength, 12% in tensile strength, 15% in modulus of elasticity, and most notably, an increase of 74% in specific fracture energy was observed in the UHPFRC mixture containing 6% steel fibers as compared to the mixture containing 4% steel fibers.

Furthermore, the workability of the mixtures was also evaluated. The results indicate that mixtures containing up to 6% steel fiber contents retained workability, while those above 6% rapidly lost workability as evidenced by the steep gradient of the declining workability line in Fig. 3a. This exhibits the natural trade-off between the mechanical properties and workability of the mixtures and that identifying the optimal balance between the two is crucial for the practical application of UHPFRC.

It is also important to highlight that the mixing and casting of specimens containing 8% and 10% by volume of fibers are extremely challenging. This difficulty in mixing and casting may lead to non-uniform distribution of fibers and inconsistent results. Therefore, it is recommended that the optimal mixture should be developed with a volume fraction of fibers equal to 6%. This will ensure efficient mixing and casting of the material and the attainment of good mechanical properties.

Investigation of the UHPFRC mixture with 6% steel fibers at different short to long denominations, yields further improvements in the mechanical properties. In this regard, one mixture containing higher contents of short fibers (ratio 5:1) and one mixture

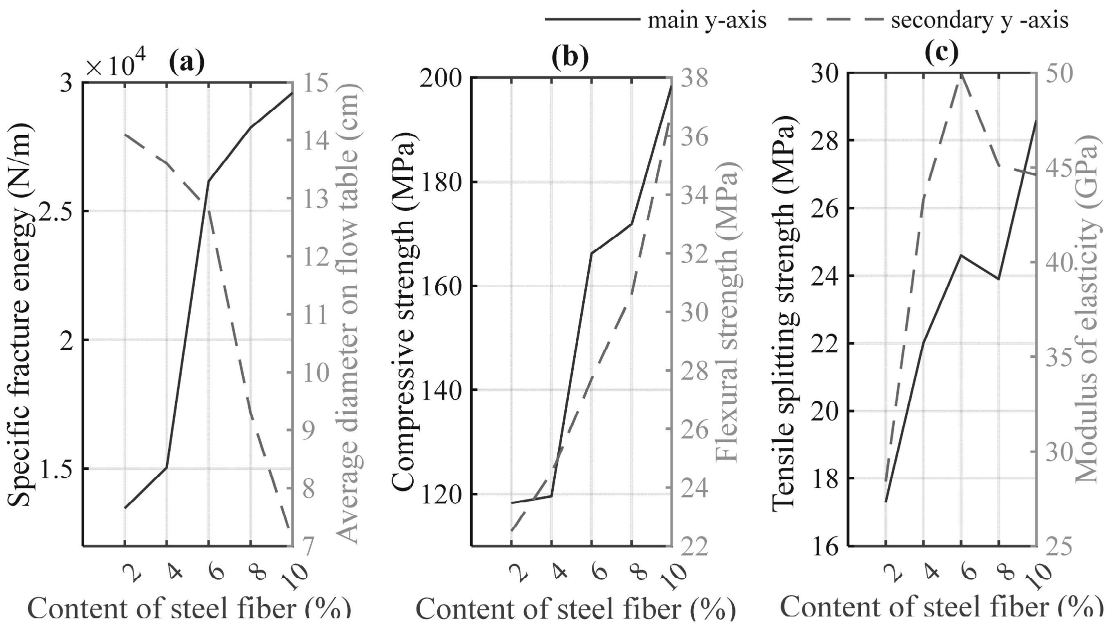

Fig. 3. (a) Specific fracture energy and average diameter on flow table, (b) 28-day compressive and flexural strength and (c) tensile splitting strength and modulus of elasticity at varied steel fiber contents (3:1 short to long)

containing equal amounts of short and long fibers (ratio 1:1) were prepared and specimens were cast, cured and tested for comparison with those developed with the nominal mixture (ratio 3:1). With reference to Fig. 4, with only exception a decline in the modulus of elasticity, mixtures containing 1:1 short to long fibers attained the best mechanical properties.

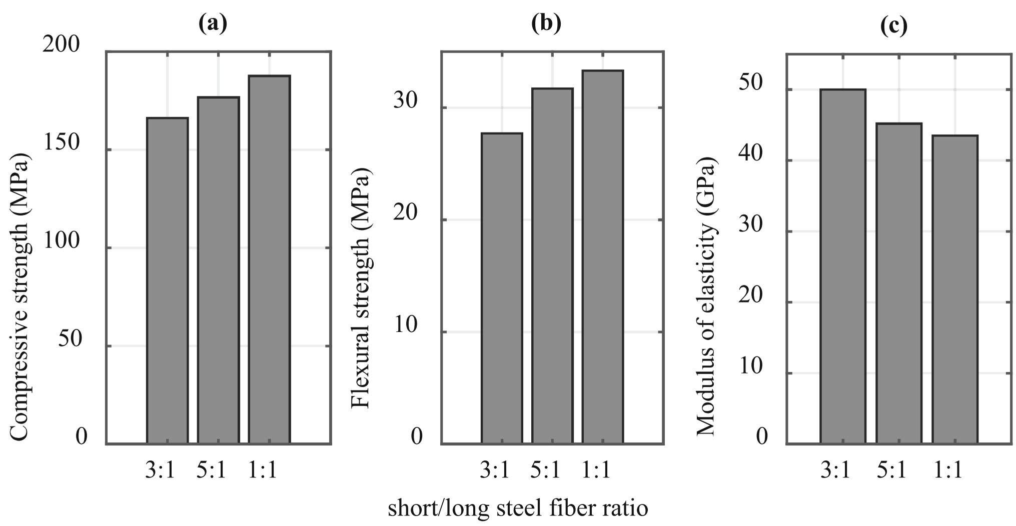

Fig. 4. (a) Compressive strength, (b) Flexural strength and (c) Modulus of elasticity at varied short to long steel fiber ratios

To investigate the effect of lower percentages of steel fibers on compressive strength, specimens were prepared with a 1:1 short to long fiber ratio and a 2% steel fiber content. Additionally, a separate group of specimens was prepared with the same fiber ratio and 2% (1:1 short/long) steel fibers, but also included 1% polyvinyl alcohol (PVA) fibers. These specimens were tested for compressive strength on the 14th and 28th day. The addition of PVA fibers was intended to reduce fiber migration during casting, which can lead to uneven distribution of fibers in the specimen. PVA fibers were chosen for this purpose due to their high modulus of elasticity and ductility.

The results, as illustrated in Fig. 5a show a significant improvement in terms of 28-day compressive strength of specimens containing 2% steel fibers (1:1) over specimens containing 2% steel fibers and a 3:1 short to long fiber distribution. The compressive strength results of the second set of specimens containing both steel and PVA fibers, as shown in Fig. 5b, demonstrate a clear superiority over the first set of specimens. Importantly, the latter set of specimens managed to achieve a 28-day compressive strength higher than 150 MPa, which is considered the threshold for impact resistance [15].

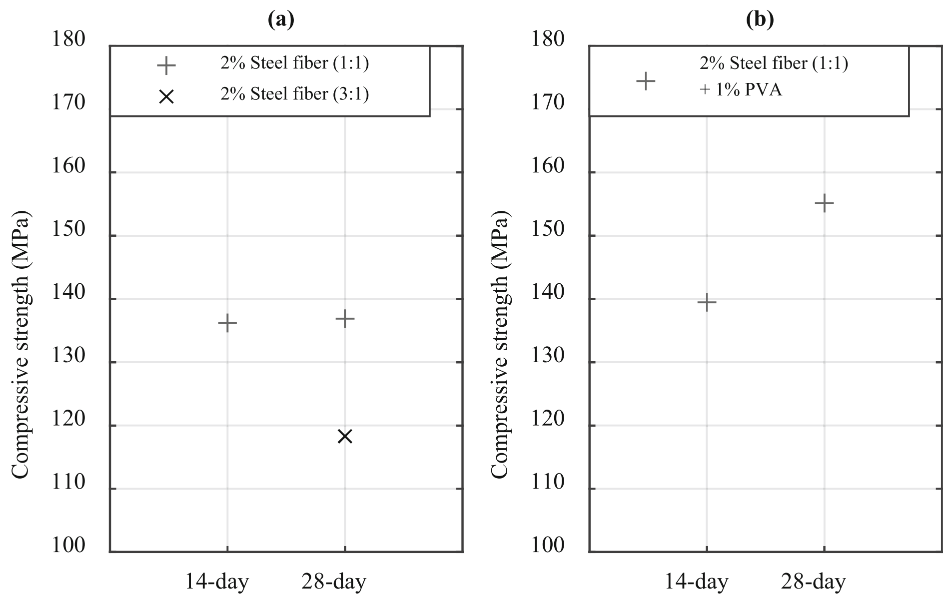

Fig. 5. (a) Compressive of mixture containing 2% steel fibers (1:1) and 2% steel fibers (3:1), (b) and mixture containing 2% steel fibers (1:1) and 1% PVA

To further minimize the amount of steel fibers in the mix, different combinations of steel to PVA fiber contents were investigated and their effect on flexural strength was evaluated. It is noteworthy that during this preliminary study, it was deemed appropriate to focus optimization efforts on low fiber contents, with flexural strength as the objective function since it is anticipated that minor fiber deviations will not significantly influence compressive strength. The results, as illustrated in Fig. 6, show that at low fiber contents, no significant gains are observed from the combined action of the two types of fibers. However, at higher fiber contents, an increase in flexural strength is evident, with the mixture containing 2% steel fibers (1:1 short/long) and 1% PVA achieving the highest flexural strength.

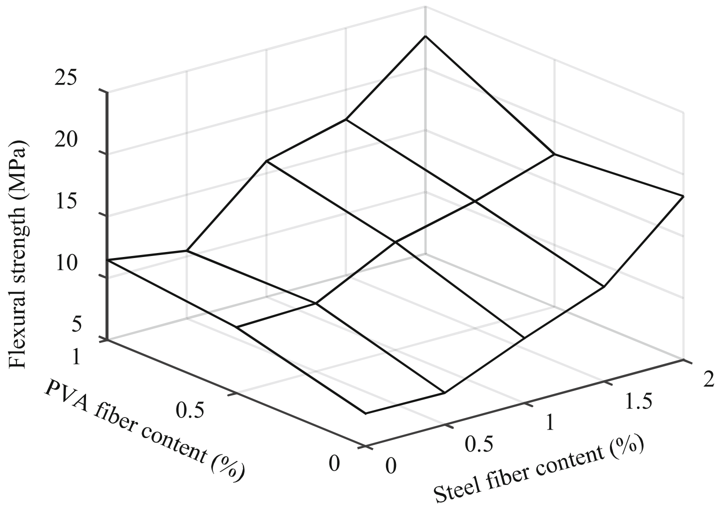

Fig. 6. Combinations of PVA and steel fiber contents and their effect on flexural strength

4 Conclusions

This study aimed to determine an optimal mixture of UHPFRC in terms of microsilica content, water curing temperature and duration, as well as monofiber steel and hybrid steel and PVA fiber contents. The results of the study showed that a microsilica content of 20%, a W/B ratio of 0.16 and 7 days of heat curing at 90 °C resulted in the highest compressive strength. Additionally, a steel fiber content of 6% with a 3:1 short to long ratio exhibited significant improvements in mechanical properties such as compressive strength, flexural strength, tensile strength, modulus of elasticity and specific fracture energy, at an apparent loss of workability and cost. The study progressed with the investigation of different volumetric fractions of short to long steel fiber contents and the results exhibited a significant increase in compressive strength when equal amounts of short and long steel fibers (1:1 ratio) are incorporated in the mixture. With these results in mind, the study re-evaluated a low percentage (2%) of steel fiber with a 1:1 short to long distribution and the results showed consistency in terms of the latter distribution outperforming the originally (3:1) considered distribution in terms of compressive strength. Importantly, with the incorporation of a single percentage of PVA fibers in the mix, the threshold of 150MPa of compressive strength set for impact resistance was able to be satisfied. Similar observations were made in terms of flexural strength where the mixture containing 2% steel and 1% PVA outperformed other combinations of low volume of fibers. The results of the study suggest that incorporating in the optimal mix a combination of steel and PVA fibers can be an effective way to improve UHPFRC mechanical properties.

Acknowledgments. The authors would like to express their sincere gratitude to the Cyprus Government and the European Regional Development Fund (ERDF) for co-funding the research project entitled "Blast and Fire Resistant Material (BAM)" (Contract Number: EXCELLENCE/0421/0137), under the framework programme RESTART 2016–2020 of the Cyprus Research & Innovation Foundation (RIF).

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Blast and Fire Resistant Material (EXCELLENCE/0421/0137)

Dr Demetris Demetriou, University of Cyprus

06th June 2023

Το έργο υλοποιείται στο πλαίσιο του Προγράμματος Πολιτικής Συνοχής «ΘΑλΕΙΑ 2021-2027» με τη συγχρηματοδότηση της ΕΕ.

Co-funded by the European Union

Republic of Cyprus

Presentation outline

Blast and Fire Resistant Material

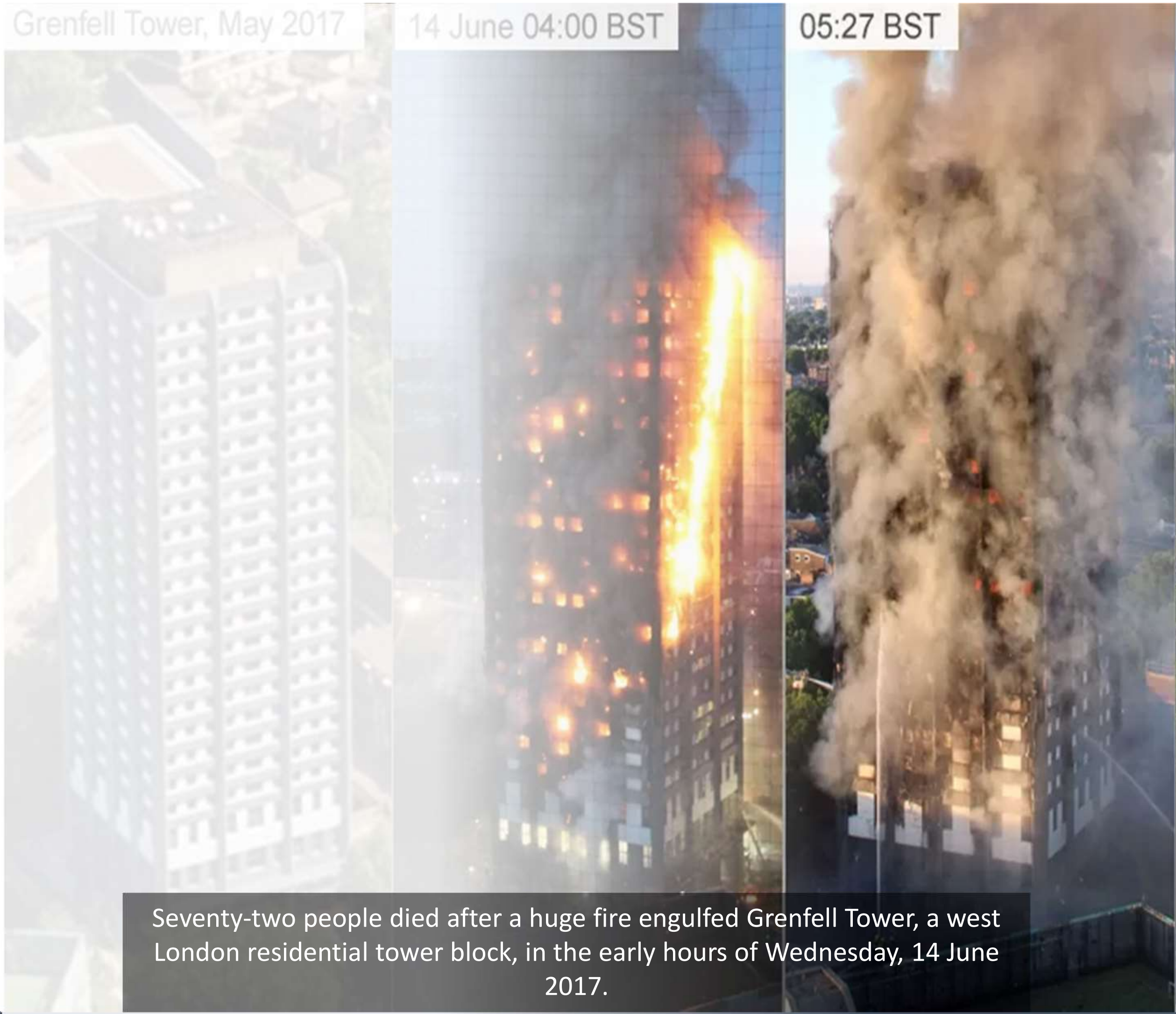
Optimizing Ultra-High-Performance Fiber-Reinforced Concrete for Impact Resistance

1. Problem definition
2. Research objectives
3. Experimental program / Results
4. Conclusions

Blast and Fire resistant material

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.

Blast and Fire resistant material

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.

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	Smart Composite Geopolymer Concrete (SCGC)

- **Objective:** To create materials that provide appropriate resistance against blast, impact, and fire, meeting relevant standards.

- Currently, no existing material possesses both fire and blast resisting properties simultaneously.

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

Smart C
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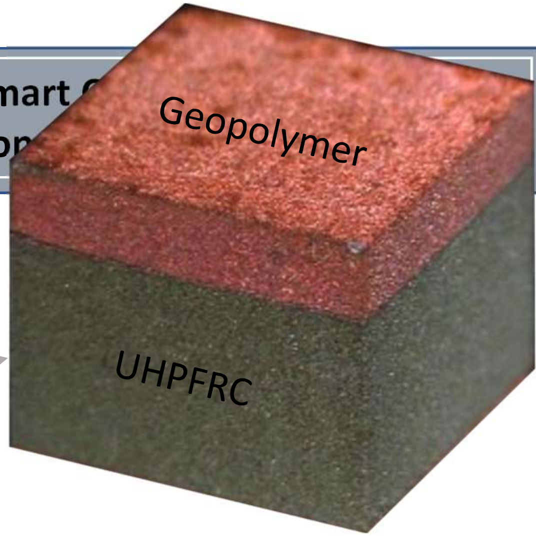

Hybrid laminated Material (HLM)

Experimental Program

Requirements:

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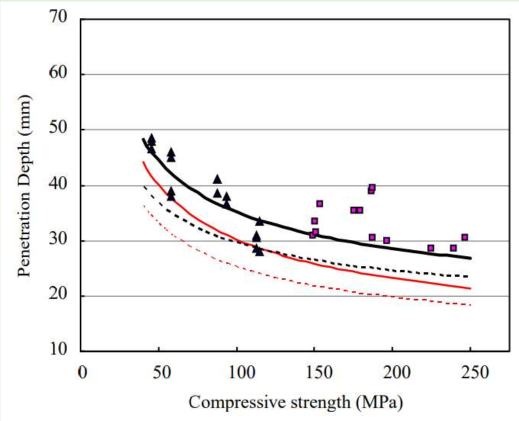

Zhang M, Shim V, Lu G, Chew C (2005) Resistance of high-strength concrete to projectile impact. International Journal of Impact Engineering 31:825-841.

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

Reference mixture:

Constituent	Content (kg/m^3)
Cement	880
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Sand 125-250μm	475
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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

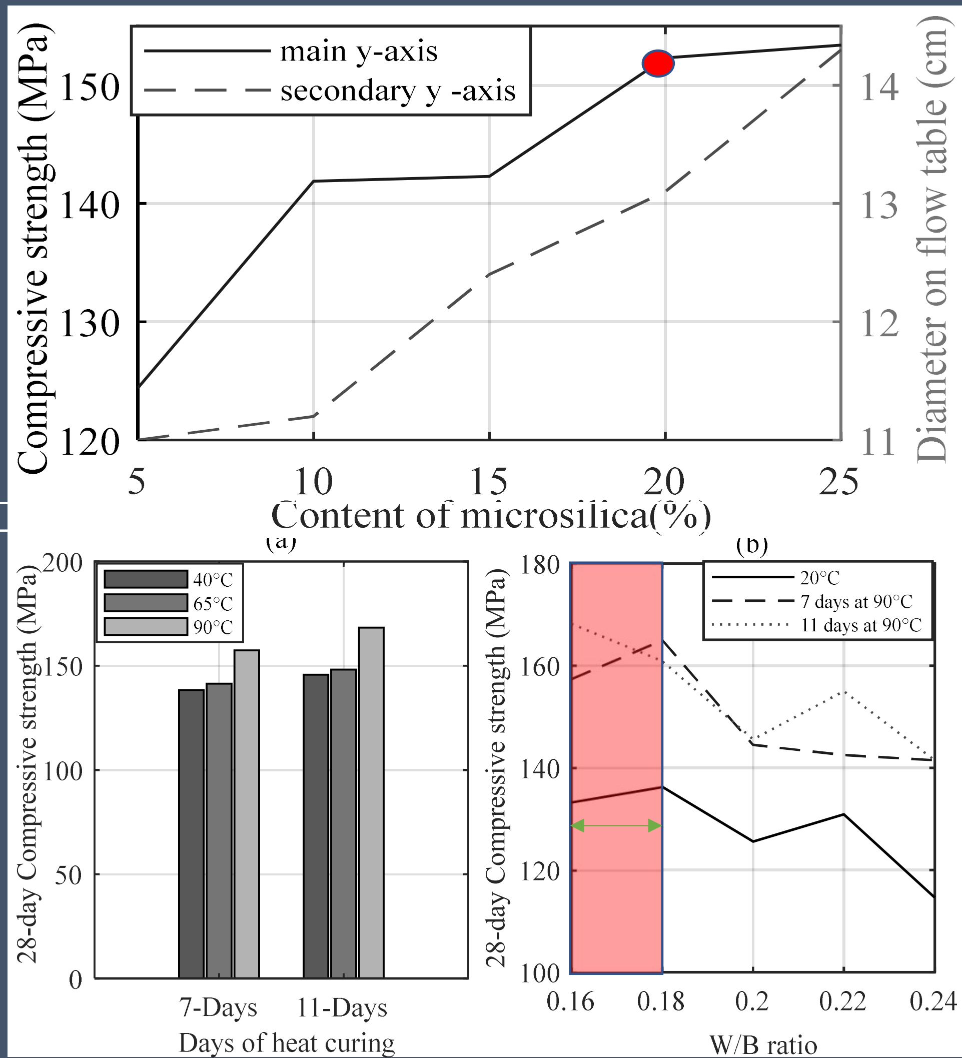
f. Proportions of fibers with different lengths

Blast and Fire resistant material

Experimental Program

Microsilica contents – Heat curing – W/B

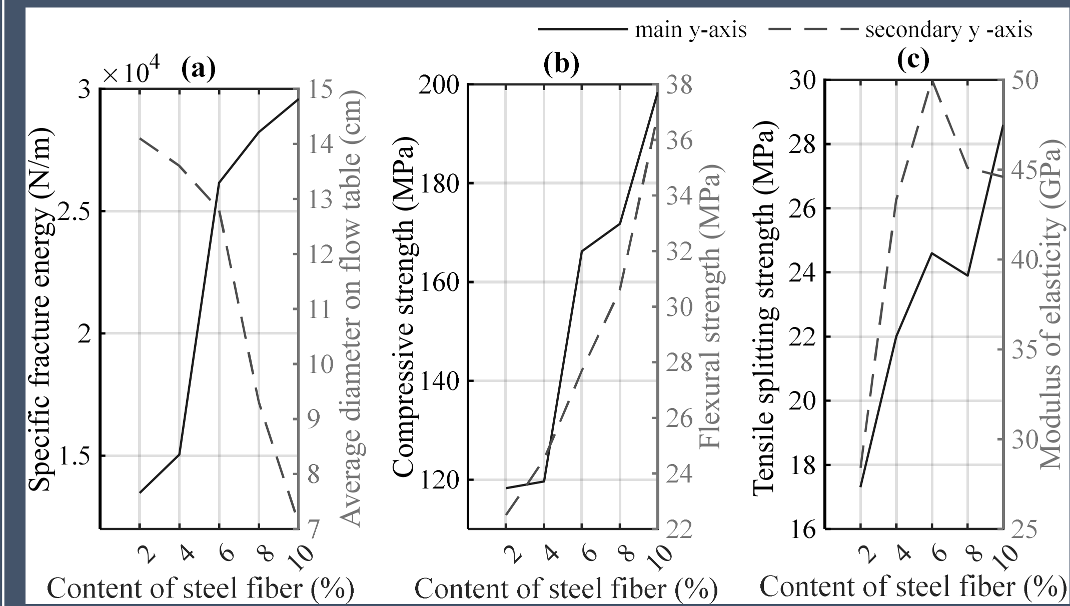
- 20% microsilica was deemed an optimal input parameter.
- 90 °C either 7 days or 11 days of water curing at elevated temperatures had higher compressive strength than those cured at lower temperatures.
- It is reasonable to propose a heat treatment duration of 7 days.
- W/B between 0.16 – 0.18 exhibit enhanced performance.



Experimental Program

Steel-fiber content optimisation (5:1 short to long)

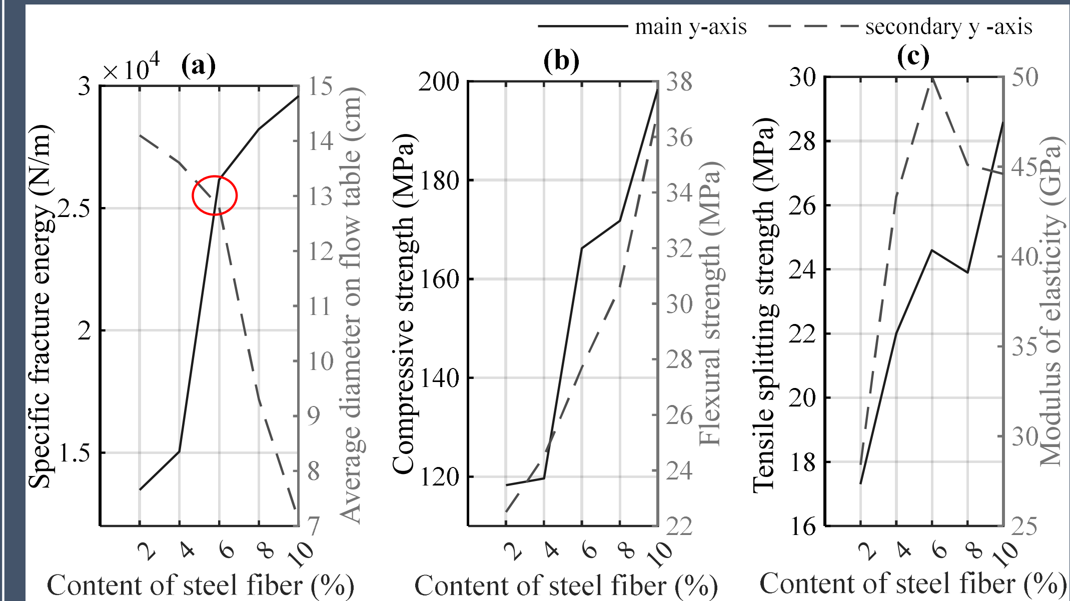
- We investigated specific fracture energy, workability, compressive, flexural, and tensile strength and modulus of elasticity
- Investigated the effect of steel fiber content (2% to 10% per volume)
- Low steel fiber contents (2-4%) showed insignificant improvement in mechanical properties, attributed to sparse fiber distribution.
- Higher steel fiber contents (up to 6%) led to further increases in all investigated mechanical properties.



Experimental Program

Steel-fiber content optimisation (5:1 short to long)

- Workability of mixtures retained up to 6% steel fiber content, while higher contents resulted in rapid loss of workability.
- Mixing and casting challenges observed with 8% and 10% fiber contents, recommending 6% as the optimal volume fraction for efficient mixing, casting, and achieving desired mechanical properties.

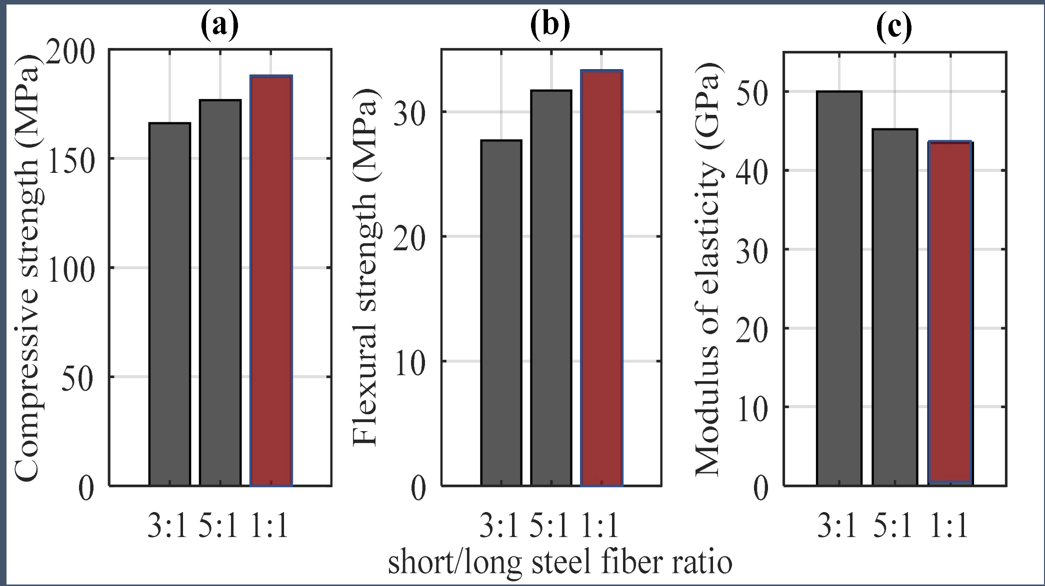


Blast and Fire resistant material

Experimental Program

Steel-fiber distribution optimisation - 1

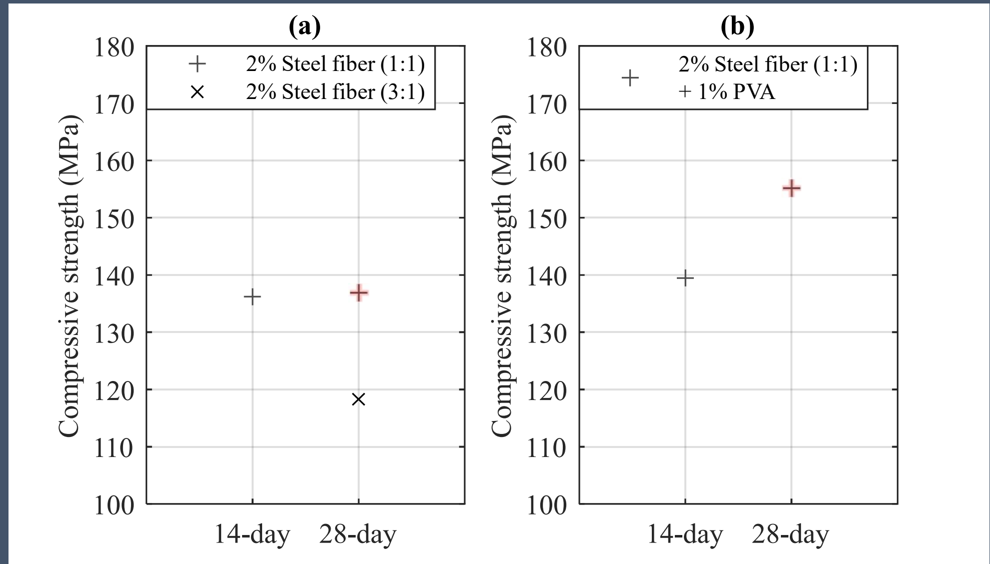
- Investigation of UHPFRC mixture with 6% steel fibers at different short to long denominations.
- Mixtures with 1:1 short to long fibers exhibited the best mechanical properties, except for a decline in modulus of elasticity.



Experimental Program

Steel-fiber distribution optimisation - 2

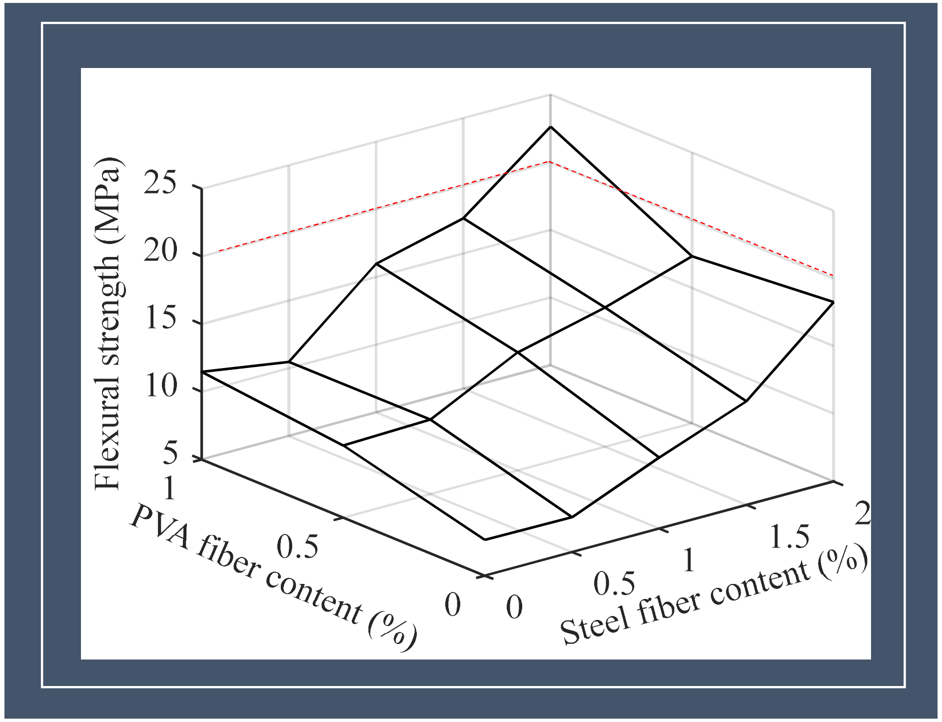
- Revisited lower contents of fibers at 1:1 short to long.
- Improved compressive strength observed for specimens with (1:1 ratio) compared to (3:1 ratio).
- Addition of PVA fibers:
  - Reinforce under reinforced areas
  - Ensuring good distribtution of fibers
  - Act as stress relief during fire preventing spalling
  - Internal curing agents
- Remarkable superiority of specimens containing both steel and PVA fibers.



Experimental Program

Steel-fiber content optimisation

- Can we lower the fiber volume while also satisfying flexural strength requirements > 20 MPa ?
- We performed optimisation of steel fiber content at low fiber volumes (<3%) at (1:1 short/long)
- Observed a significant increase in strength with the addition of 2% steel fiber and 1% PVA in the mixture



Blast and Fire resistant material

Experimental Program

Impact tests

Experimental Program

Impact tests and numerical simulations

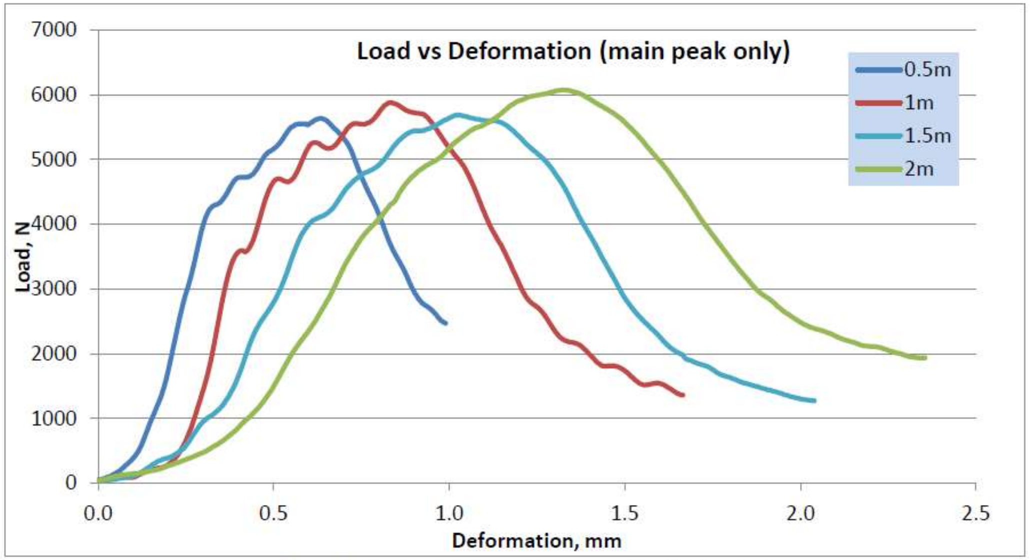
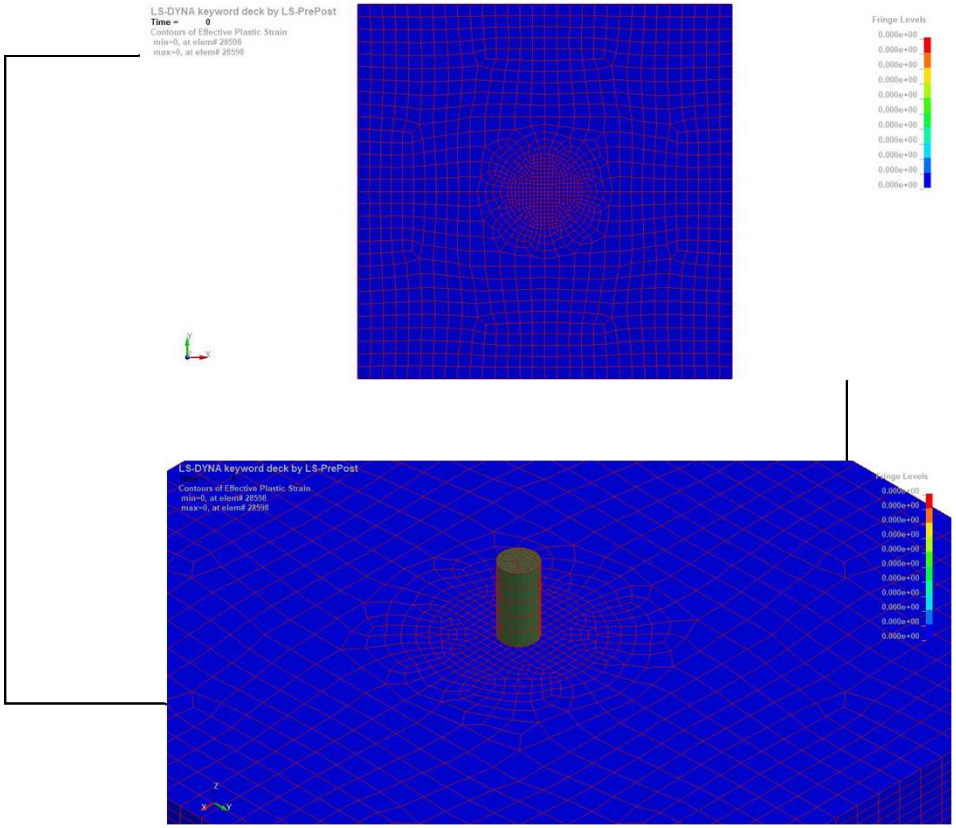


Figure 3. The load-deformation curves for the four tests.



Blast and Fire resistant material

Conclusions

1	2	3	4
Microsilica contents Heat Curing W/B Volume and distribution of fibers	Hybrid Steel & PVA Important in achieving the requirements for impact resistance	Numerical models to help to iteratively improve mix design for the specific application	Investigation of internal curing in UHPFRC mixtures containing PVA

Acknowledgements

Co-funded by the European Union

Republic of Cyprus

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.

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PROGRAMME

2B05: Structural performance-seismic response — HALL 4
Session Chairs: Roberta Apostolska, Erkan Akpınar

12:00-12:15 **1277** - Shaking table test of a 1/4-scale self-centering precast reinforced concrete frame
Yang Li, *Xilin Lu*

12:15-12:30 **1130** - Multi hazard risk assessment of basic services and transport infrastructure in RN Macedonia, Greece and Albania cross-border region – CRISIS project
Roberta Apostolska, *Vlatko Sheshov, Radmila Salic, Marija Vitanova Julijana Bojadzieva, Kemal Edip, Marta Stojmanovska, Aleksandra Bogdanovic, Barbara Borzi, Elisa Zuccolo, Francesca Bozzoni, Antonella Di Meo Dimitrios Pitilakis, Evi Riga, Stavroula Fotopoulou, Christos Petridis, Stevko Stefanoski, Neritan Shkodrani, Markel Baballëku*

12:30-12:45 **1198** - Large-Scale Tests on RC Purpose-Built Buildings for Improving Robustness
Jose Adam*, Manuel Buitrago], Nirvan Makoond Eduardo J. Mezquida-Alcaraz*

12:45-13:00 **1519** - Influence of surface topography on seismic response of existing buildings
Yavuz Deniz*, Zeynep Tuna Deger, Wenyang Zhang and Ertugrul Taciroglu*

13:00-13:15 **1188** - Metallic Dissipaters Made of Conventional and Advanced Materials for Seismic Protection of Structures
Mustafa Mashal, *Mahesh Acharya, Jared Cantrell and Saksham Raj Maharjan*

13:15-13:30 **1282** - Shaking Table Test of a Single-Tube Structure with Peripheral Suspended Floor Systems
Wenjun Gao, *Xiaofang Wen, Bin Zhao,, Xilin Lu*

13:30-13:45 **1078** - Development of a Deep Learning-Based Anomaly Detection System for Structures
Mehboob Rasul, *Manabu Kawashima1 and Khuyen Trong Hoang*

2B06: Performance of fiber renforced concrete/composite — HALL 5
Session Chairs: Michael F. Petrou, Savaş Erdem

12:00-12:15 **1083** - Numerical Simulation of Casting Process of Fiber Reinforced Self-Compacting Concrete (SCC)
Guomin Ji, *Mohammad Abedi, Chen Lin*

12:15-12:30 **1492** - Strain Hardening Cementitious Composite (SHCC) in reinforced concrete cover zone for crack width control
Shan He, *Mladena Luković, Erik Schlangen*

12:30-12:45 **1403** - Optimising Ultra-High-Performance Fiber-Reinforced Concrete for Impact Resistance
Michael F. Petrou, *Demetris Demetriou, Thomaida Polydorou, Konstantina Oikonomopoulou, Pericles Savva, Ioanna Giannopoulou, Ponsian M. Robert, Ourania Tsiolou, Andreas Lampropoulos , Demetris Nicolaides*

12:45-13:00 **1452** - Hemp Fiber Reinforced Lightweight Concrete (HRLWC) with Supplementary Cementitious Materials (SCM)
Havva Merve Tuncer, *Zehra Canan Girgin*

13:00-13:15 **1021** - The Mechanical Effects of Recycled Steel Fiber on Concrete
Cansu Colak, *Ozkan Sengul*