

## MSFA & FRCA Position Paper on Fibre-Reinforced Concrete made with Steel or Synthetic Macrofibres

### INTRODUCTION

Fibres have been widely used to reinforce brittle materials. In modern construction, fibres are added to concrete to reduce its brittleness. Fibre-reinforced concrete (FRC) is a composite material that includes the use of fibres whether in lieu of traditional reinforcement or in addition to it. Fibres are classified into four different categories - steel, alkali-resistant glass, synthetic and natural fibres – and come in different types of configurations and sizes. They typically range from 6 mm to 65 mm (1/4" - 2½") in length and are classified as either microfibres or macrofibres based on their equivalent diameter. Depending on type, characteristics and dosage, fibres can provide unique benefits in either fresh or hardened concrete, or both.



*Macro synthetic fibre reinforcement in concrete.*

By far, one of the most important benefits of fibres is the significant increase in ductility and toughness (a measure of energy absorption capacity) and the post-peak, post-crack load-carrying capacity that they can provide in hardened concrete. Consequently, fibres, particularly steel and synthetic macrofibres,

are being used widely in various applications worldwide stemming from the need for economically viable concrete with increased toughness and durability. These applications include slab-on-ground, mining and tunnelling, excavation support work, and precast concrete applications. Furthermore, the use of synthetic macrofibre is rapidly increasing worldwide as an increasing number of designers and contractors recognize their ability to meet design performance requirements and their cost-effectiveness compared to other alternatives.

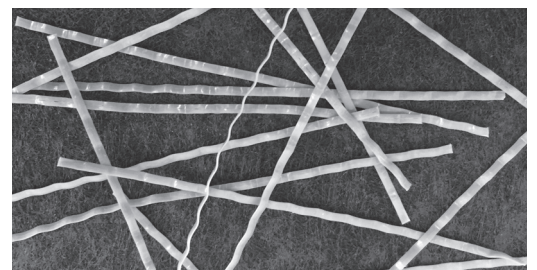
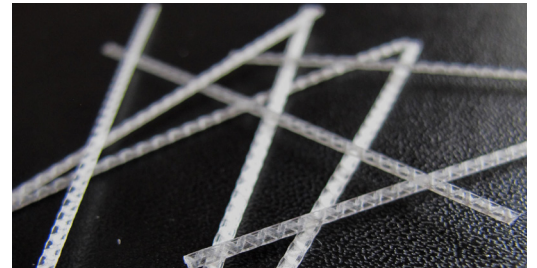
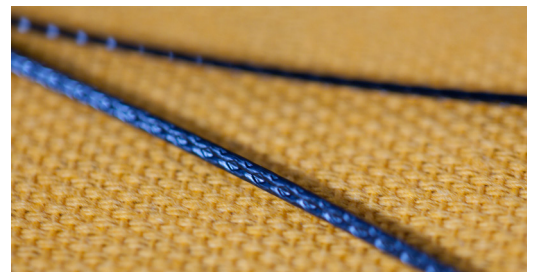
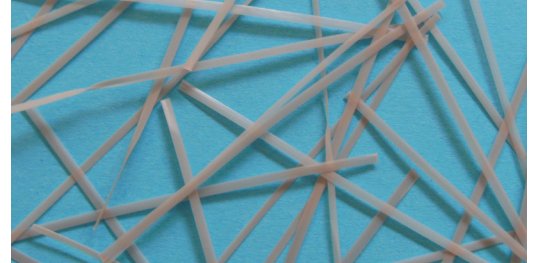
Unfortunately, for competitive reasons, biased and misleading information or claims are sometimes made against synthetic macrofibres. This position paper has been developed jointly by the Macro Synthetic Fibre Association (MSFA) and the Fiber Reinforced Concrete Association (FRCA) to provide more accurate and unbiased comparison of the performance and benefits of steel fibre-reinforced concrete (SFRC) and synthetic macrofibre-reinforced concrete (MSFRC).

# Fibre Physical Performance and Characteristics

All fibres - microfibres, and macrofibres - have unique characteristics that depending on the application will determine their selection and use. However, users should not simply focus on the physical characteristics of a fibre in deciding what fibre to use, but rather select a fibre based on the performance requirements of the intended FRC mixture and overall in-place cost.

To put this in perspective, it should be noted that fibres typically make up only about 0.05 to 1% by volume of a FRC mixture and, therefore, it is the properties of the resultant FRC mixture that matters, not simply the properties of the material from which the fibre is made. Fibres do not act by themselves in isolation, they simply modify and enhance the properties of the concrete in which they are distributed.

In addition to tensile strength, Young's modulus of elasticity and fibre geometry, the volume fraction of fibre also influences the reinforcing ability of a fibre. It is true that, relative to steel fibres, synthetic fibres have lower Young's modulus of elasticity, tensile strength and specific density. However, contrary to the biased and misleading information that have been circulated, this does not mean that synthetic macrofibres cannot meet the performance requirements of FRC for use in slab-on-ground, mining and tunnelling, precast elements and excavation support work. Due to their lower specific density, the fibre count for synthetic macrofibres per unit volume and, therefore, the number of fibres across a given cross-section of FRC are significantly higher than that for steel macrofibres. In other words, in MSFRC the post-crack load is carried by a lot of synthetic macrofibres compared to a relatively few steel macrofibres in SFRC; and, MSFRC can provide performance equivalent to that of SFRC. Some of the typical questions asked by the industry when comparing synthetic and steel macrofibres are as follows:



# 01

## Can synthetic macrofibres be used as structural reinforcement in FRC?

Synthetic macrofibres are able to provide structural reinforcement of concrete and this is noted in the overview of European Standard EN 14889-2:2006, “Fibres for concrete. Polymer fibres. Definitions, specifications and conformity,” shown below.

“This Part 2 of EN 14889 specifies requirements for polymer fibres for structural or non-structural use in concrete, mortar and grout. NOTE Structural use of fibres is where the addition of fibres is designed to contribute to the load bearing capacity of a concrete element. This standard covers fibres intended for use in all types of concrete and mortar, including sprayed concrete, flooring, precast, in-situ and repair concretes.”

When their use is intended to enhance the load-carrying performance of concrete, all steel and synthetic macrofibre products are tested to meet Level 1 of the Attestation of Conformity in independent laboratories and completely satisfy the requirements of European Standard EN 14889:2006 Parts 1 & 2. The requirements for testing both steel and macro synthetic fibres intended for structural applications are identical. Therefore, the user can have upmost confidence that the information they are provided is directly comparable. It should be noted that EN 14889-1:2006 is the companion standard for steel macrofibres.

In North America, independent of fibre material type, ASTM C1609/C1609M, “Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam with Third-Point Loading)” and ASTM C1550, “Standard Test Method for Flexural Toughness of Fiber Reinforced Concrete (Using Centrally Loaded Round Panel),” are used to assess the flexural performance and flexural toughness, respectively, of FRC. Performance requirements based on these standard test methods are specified in FRC projects and dosages of either synthetic or steel macrofibres are determined accordingly. In addition, there are two ASTM International standard specifications specific to precast concrete pipes, ASTM C1765, “Standard Specification for Steel Fiber Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe” and ASTM C1818, “Standard Specification for Synthetic Fiber Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe” that stipulate the performance requirements that have to be met to replace conventional steel in reinforced concrete pipes with either steel or synthetic macrofibres.





## 02

### **“Will designing a floor or tunnel lining with synthetic macrofibre concrete based on post-crack strength lead to large crack openings, major concrete deformations, or possibly failure depending on loads?”**

All engineering solutions, including conventional reinforced concrete and SFRC, can result in such issues if not designed correctly and within the limits of the chosen materials. Fibre suppliers typically provide design solutions in accordance with independent technical guides such as the UK Concrete Society Technical Report N° 34 (TR34), ACI 544.4R, ACI 360R-10 and ITAtech report No.7 (April 2016) to justify macrofibre dosage recommendations. Structural design guidelines such as RILEM TC 162-TDF and, more recently, the fib Model Code 2010, detail the general

design of fibre reinforced concrete structures. The composite material FRC must satisfy the performance requirements of the structure, which is independent from the fibre material. Both SFRC and MSFRC have been used successfully in slabs-on-ground, mining and tunnelling, excavation support work, and precast concrete applications, and some of these projects are documented by the MSFA and FRCA at the following links:

<https://msfassociation.com/case-studies/>;

<https://fiberreinforcedconcrete.org/resources/project-case-studies/>.

## 03

### **“Do synthetic macrofibres creep?”**

To state that synthetic macrofibres creep is a very misleading statement since all materials tend to exhibit measurable creep dependent on load level. In addition, most commercial macrofibres are designed to pull-out of the concrete before failing in tension, so the long-term resistance to pull-out under load becomes much more important. It is obviously important that the effects of creep are fully understood and, if relevant, considered in a design. However, it should be noted that it is the performance of the FRC as a composite material in creep, not just the individual characteristics of the isolated fibre material, that is of importance. RILEM TC 261-CCF concludes in one of its 2016 workshop papers that the influence of fibres is on the flexural toughness of the composite material, which in turn

affects the creep response. It is worth noting that FRC is frequently used in applications where creep is not a design consideration or where it can be adequately accounted for within the overall design of the concrete element in question. In fact, Plizzari and Serna (2018) concluded that FRC creep has a negligible role in most current applications where it is adopted. Most of the critical elements mentioned concerning creep are linear elements that do not allow for stress redistribution. Appropriate creep behaviour of the FRC composite material, not only the fibre, needs to be shown if conventional rebars are to be replaced completely by macrofibres in an application. Engineers should take all material properties into consideration when looking at specific design solutions.

## 04

### **“Synthetic fibres melt at 165 °C; is that a concern?”**

High temperatures resulting from fires are a problem to most materials including synthetic and steel fibres and indeed concrete itself. Polypropylene, the polymer predominantly used in the manufacture of synthetic fibres, melts at 165 °C and fibres at or near the surface of the concrete will melt if the concrete surface temperature reaches and exceeds this value. This is actually a positive factor and the reason why synthetic microfibres provide resistance against the explosive spalling of concrete in fires, even with SFRC, which itself loses its tensile performance at 300 °C, according to DBV 2001.

Since concrete is a poor conductor of heat, there will be a temperature gradient from the concrete surface through the depth of the concrete section. Therefore, further into the concrete the temperature would be much lower than the fire temperature and not high enough to melt synthetic fibres, except in a severe high-temperature fire event where concrete spalling leads to loss of protective surface. In such a fire event, the concrete itself is likely to suffer significant deterioration either through explosive spalling or thermal damage and will lose its structural integrity. The presence of either steel or synthetic macrofibres will have little beneficial effect in this scenario and generally all tunnel linings will need some repair after a severe fire, independent from the type of reinforcement and the presence of synthetic microfibres.

## 05

### **“UV rays can degrade polypropylene; is that a concern for synthetic macrofibres?”**

This is another example of where the individual material property is completely irrelevant regarding the performance of the MSFRC composite material. It is true that UV rays can degrade polypropylene that is exposed to direct sunlight. However, in MSFRC the fibres are completely embedded in the concrete where UV light cannot penetrate, so this is not an issue. Furthermore, good quality macro synthetic fibres will have an UV stabilizer in their composition so that even near-surface fibres do not suffer deterioration. To date, millions of square meters of MSFRC have been applied in roads, pavements, car parks, industrial floors, slope stabilization, etc., and no issues related to UV degradation of the polymer fibres have been reported.

# 06

## “Are synthetic fibres durable?”

This concern regarding the durability of synthetic fibres needs to be addressed in the proper context with respect to fibres made from polyolefins (polyethylene and polypropylene). The following excerpt from USACERL Technical Report FM-93/02, “Synthetic Fiber Reinforcement for Concrete,” a technical report dated November 1992 from the U.S. Army Corps of Engineers describes the chemical durability of synthetic fibres.

“Cement paste develops a moist alkaline environment detrimental to many organic materials. The minimum pH in a cement paste is about 12.3, which corresponds to a saturated calcium hydroxide solution. However, many modern cements have high alkali (sodium and potassium) contents, which can raise the pH to 13.5 or greater when the cement is mixed with water. This corresponds to about 0.6M sodium hydroxide (NaOH). This very high pH will be detrimental to some polymers. Polyesters, polyacrylics, and polyamides are particularly sensitive since they can undergo alkaline hydrolysis. Hydrolysis may be slow at room temperature but may be significantly accelerated at higher temperatures. In studies on polyacrylic fibres only slight loss of strength at 20 °C was observed after 2 months, but a significant loss at 50 °C occurred in the same period (Wang, Backer, and Li 1987). By contrast, the hydrophobic nature of polyethylene and polypropylene fibres makes them quite resistant to alkaline conditions.”

Consequently, one of the recommendations provided in the report stated that “synthetic fiber reinforcement to be used in concrete that will be subjected to prolonged conditions of high humidity should be composed of alkali-resistant synthetic fibres such as polypropylene or polyethylene.”

Synthetic fibres have been used as concrete reinforcement for many years and their durability

in concrete have been studied and reported, including an 18-year study of polypropylene fibres in cement composites by Prof. D.J. Hannant. The paper titled “The effects of age up to 18 years under various exposure conditions on the tensile properties of a polypropylene fibre reinforced cement composites,” was published in *Materials and Structure* (Vol. 32, March 1999, pp 83-88) with the following abstract that demonstrates the durability of polypropylene fibres.

“An 18-year test programme has been completed on the tensile stress strain performance cement composites reinforced with two types of polypropylene fibrillated networks. Three storage conditions have been used – natural weathering, storage inside in laboratory air, and under water storage. Some composites have been pre-cracked before exposure and others left uncracked before testing. The parameters measured included the elastic modulus and cracking stress of the matrix, complete tensile stress-strain curves and crack distribution in the composite, and the effects of the different weathering conditions on the tensile strength, strain to failure and bond strength of the polypropylene reinforcement. In general terms, it was shown that where the fibre volume remained above the critical fibre volume, the strength, durability and toughness of the composite was maintained regardless of exposure conditions for very long periods of time. In particular, the material has remained ductile, with a failure strain in excess of 5% after 18 years under water, which is unusual for fibre reinforced cement composites.”

Finally, it is noted in ASTM C1116/C1116M, “Standard Specification for Fiber-Reinforced Concrete,” that “fibers such as polyolefins (polypropylene and polyethylene), nylon, and carbon have been shown to be durable in concrete.”

## Closing

One of the driving forces behind the development of synthetic macrofibres was to create a viable alternative to steel macrofibres frequently used in shotcrete applications. Over the last two decades, macro synthetic fibres have become a cost-effective viable reinforcement option for design engineers and contractors alike, being a proven technology. Indeed, in sprayed concrete applications such as mining, tunnelling and slope stabilization they are rapidly becoming the material of choice and the same trends

exist with slabs-on-ground and precast elements, including tunnel segments.

Members of the MSFA and FRCA have over 25 years of experience supplying and supporting the successful use of macro synthetic fibres to the market. The member companies of the two associations stand committed to working together and with designers, contractors and concrete producers to further increase the market acceptance of macro synthetic fibres.

## References

ACI 360R-10, Guide to the Design of Slabs-on-Ground, American Concrete Institute, Farmington Hills, MI, 2010, 72 pages. (ISBN: 9780870313714)

ACI 544.4R-18, Guide to Design with Fiber-Reinforced Concrete, American Concrete Institute, Farmington Hills, MI, 2018, 44 pages. (ISBN: 9781641950190)

ASTM C1116 / C1116M-10a(2015), Standard Specification for Fiber-Reinforced Concrete, ASTM International, West Conshohocken, PA, 2015, [www.astm.org](http://www.astm.org)

ASTM C1550-19, Standard Test Method for Flexural Toughness of Fiber Reinforced Concrete (Using Centrally Loaded Round Panel), ASTM International, West Conshohocken, PA, 2019, [www.astm.org](http://www.astm.org)

ASTM C1609 / C1609M-19a, Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam with Third-Point Loading), ASTM International, West Conshohocken, PA, 2019, [www.astm.org](http://www.astm.org)

ASTM C1765-19, Standard Specification for Steel Fiber Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe, ASTM International, West Conshohocken, PA, 2019, [www.astm.org](http://www.astm.org)

ASTM C1818-19, Standard Specification for Synthetic Fiber Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe, ASTM International, West Conshohocken, PA, 2019, [www.astm.org](http://www.astm.org)

EN 14889-2:2006, Fibres for concrete. Polymer fibres. Definitions, specifications and conformity, British Standards Institution, Sep. 2006.

fib Model Code for Concrete Structures 2010, fédération internationale du béton/International Federation for Structural Concrete (fib), Oct. 2013. (Print ISBN:9783433030615 | Online ISBN:9783433604090)

Garcia-Taengua, E., Llano-Torre, A., Marti-Vargas, J.R., and Serna, P., "Effect of Residual Strength Parameters on FRC Flexural Creep:

Multivariate Analysis," Proceedings of the International RILEM Workshop on Creep Behaviour in Cracked Section of Fibre Reinforced Concrete, Serna P., Llano-Torre A., Cavalaro S. (eds), Valencia, March 9-10, 2016, pp. 141-153.

Hannant, D.J. "The effects of age up to 18 years under various exposure conditions on the tensile properties of a polypropylene fibre reinforced cement composites," *Materials and Structure*, Vol. 32, March 1999, pp. 83-88 (<https://doi.org/10.1007/BF02479433>)

ITAtch Report No.7, "ITAtch Guidance for Precast Fibre Reinforced Concrete Segments – Vol. 1: Design Aspects," ITAtch, Apr. 2016. (ISBN: 978-2-9701013-2-1)

Ludirdja, D., Young, J.F. and U.S. Army Corps of Engineers Construction Engineering Research Laboratory, "Synthetic Fiber Reinforcement for Concrete [microform]," USACERL Technical Report FM-93/02, National Technical Information Service, distributor Champaign, IL: Springfield, VA, Nov. 1992.

Plizzari, G. and Serna, P., "Structural Effects of FRC Creep," *Materials and Structures*, 2018, pp. 51–167.

RILEM TC 162-TDF: "Test and design methods for steel fibre reinforced concrete," *Materials and Structures / Matériaux et Constructions*, Vol. 36, Oct. 2003, pp. 560-567.

Steel fibre concrete: [DBV - Guide to Good Practice], DBV-Merkblatt Stahlfaserbeton, Ausgabe Oktober 2001 (German Concrete Association, Final Edition, Oct. 2001)

Technical Report 34 (TR34): Concrete Industrial Ground Floors, Fourth Edition, The Concrete Society, March 2016. (ISBN 978-1-904482-77-2)

Wang, Y., Backer, S., and Li, V.C., "An Experimental Study of Synthetic Fibre Reinforced Cementitious Composites," *Journal of Materials Science*, Vol. 22, 1987, pp. 4281-4291.



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The Macro Synthetic Fibre Association (MSFA) is committed to the development of international standards and guidelines for the use of macro synthetic fibre concrete reinforcement.

The MSFA is the leading authority on the safe use and development of macro synthetic fibre concrete reinforcement in international markets.

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