

Effects of Synthetic Macrofibers on Fresh Concrete and their Implications

Introduction

Synthetic macrofibers, typically referred to as macrosynthetic fibers, are being used more and more in concrete mixtures. Some of the most common applications for macrosynthetic fibers include slab-on-ground and sprayed concrete (shotcrete) where they are used to provide post-crack reinforcement in lieu of traditional temperature and shrinkage steel reinforcement. ACI 544.3R (1) defines macrosynthetic fibers as having diameters or equivalent diameters greater than 0.012 in. (0.3 mm). This, however, does not characterize them sufficiently.

Macrosynthetic fibers come in different forms and sizes and, therefore, have varying effects on the fresh and post-crack properties of hardened concrete (2). As a result, the effects of macrosynthetic fibers on the placement, consolidation and finishing of fresh concrete may, and often do, vary from fiber to fiber. This may require adjustments in mixture proportions, in particular, admixture dosages.

This bulletin highlights the effect of fiber type and dosage on the rheological properties of fresh concrete and high-range water-reducing admixture demand.

Macrofiber Characteristics

- ACI 544.1R (3) provides a glossary of the terms typically used to describe fibers. These include the following:
- Aspect ratio – the ratio of length to diameter of the fiber. Diameter may be equivalent diameter.
- Collated – fibers bundled together either by cross-linking or by chemical or mechanical means.
- Denier – weight in grams of 9000 meters of a single fiber.
- Fibrillated – a slit film fiber where sections of the fiber peel away, forming branching fibrils
- Fiber count – the number of fibers in a unit volume of

concrete matrix.

- Post-mix denier – the average denier of fiber as dispersed throughout the concrete mixture (opened fibrils).
- Pre-mix denier – the average denier of fiber as added to the concrete mixture (unopened fibrils).

Fiber count is typically calculated using one of two equations provided in ACI 544.1R taking into consideration fiber dosage, length, equivalent diameter, specific gravity and post-mix denier.

In addition to the terms provided in the ACI 544.1R glossary, the following terms are provided in this bulletin to further characterize fibers.

- Fiber Architecture – the geometry of the fiber.
- Fiber Rigidity – the ability of the fiber to resist bending or deformation
- Fiber Alteration – the post-mix denier relative to the pre-mix denier.

The architecture of macrosynthetic fibers falls into three primary categories as shown in Fig. 1.



Figure 1. Fiber Architecture

Figure 2 shows two fibers – a twisted rope fiber (Photo A) and a collated tape fiber (Photo B) – that alter their denier during mixing. In each photo, the fiber prior to mixing is shown on the left. Fiber alteration can occur for fibers that are bundled, collated, fibrillated or serrated.

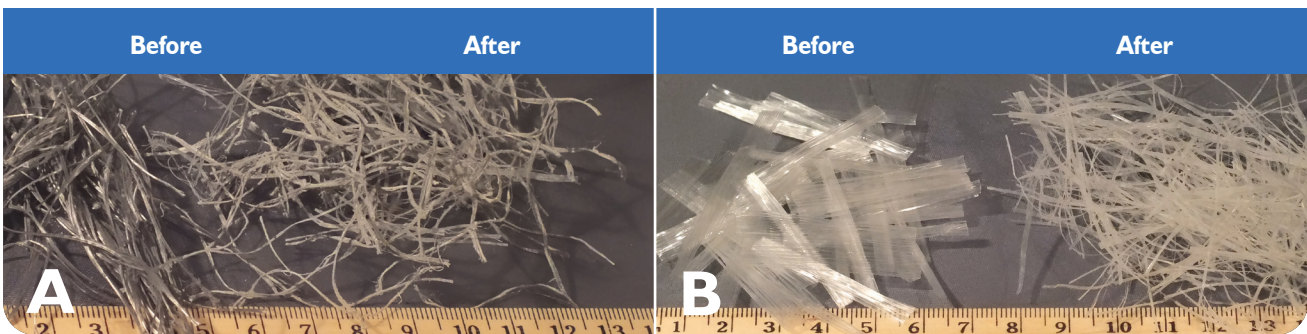


Figure 2. Examples of Fiber Alteration

Influence of Macrofiber Type on Rheological Properties of Concrete and Admixture Dosage

When fibers are added to a concrete mixture, the slump of the concrete typically decreases. In addition, as noted in ACI 238.1R (4), the inclusion of fibers will increase both the yield stress and plastic viscosity of a concrete mixture. In other words, if no mixture adjustments are made, fibers may influence the ease with which a concrete mixture is placed, consolidated and finished. To compensate for the decrease in slump, the water-reducing admixture dosage is either increased or more water is added to the concrete mixture. Depending on the option used, mixture cost may be increased or strength may be compromised.

As noted earlier, macrosynthetic fibers will have varying degrees of influence on fresh concrete properties due to differences in architecture. To demonstrate this, Master Builders Solutions conducted a study to evaluate the effects of five different macrosynthetic fibers on 1) rheological properties (yield stress and plastic viscosity); and, 2) the dosage of high-range water-reducing admixture (HRWRA) required to achieve a target slump. All five fiber types were evaluated in

both a conventional slab-on-ground mixture and a mixture proportioned for extended joint spacing applications. As shown in Table 1, with the exception of one fiber that has chemical-bonding (CB) properties, each fiber was evaluated at a dosage of 5.0 lb/yd³ (3.0 kg/m³) in the conventional mixture and 7.5 lb/yd³ (4.5 kg/m³) in the extended joint spacing mixture. The corresponding dosages for the CB fiber, based on equivalent post-crack flexural performance, were 3.6 lb/yd³ (2.1 kg/m³) and 6.0 lb/yd³ (3.6 kg/m³), respectively.

For comparison purposes, a reference concrete mixture without fibers was evaluated for each concrete type, and for all mixtures the HRWRA dosage was adjusted to achieve a slump of 6 ± 1 in. (150 ± 25 mm). Slump was measured in accordance with ASTM C 143/C 143M and concrete rheological measurements were made using an IBB Rheometer (5).

The relative effects of macrosynthetic fiber type on HRWRA dosage and plastic viscosity are summarized in Fig. 3 and 4, respectively.

Table I – Fiber Dosage by Mixture Type

	Conventional Mixture lb/yd ³ (kg/m ³)	Extended Joint Spacing Mixture lb/yd ³ (kg/m ³)
Stick, CB	3.6 (2.1)	6.0 (3.6)
Stick	5.0 (3.0)	7.5 (4.5)
Rope, Non-altering	5.0 (3.0)	7.5 (4.5)
Rope, Altering	5.0 (3.0)	7.5 (4.5)
Tape, Non-altering	5.0 (3.0)	7.5 (4.5)

Increase in HRWRA Dosage vs. Non Fiber

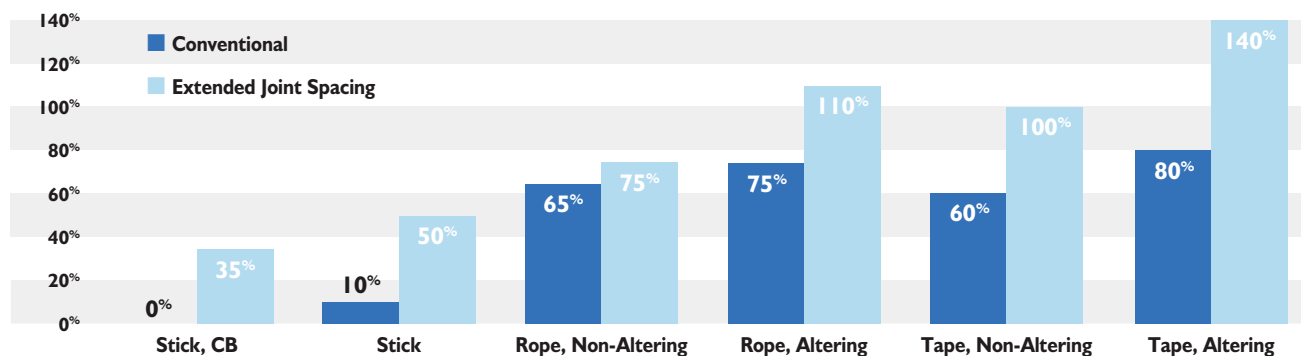


Figure 3. Increase in HRWRA dosage by macrosynthetic fiber type

Plastic Viscosity Increase vs. Non Fiber Mixture

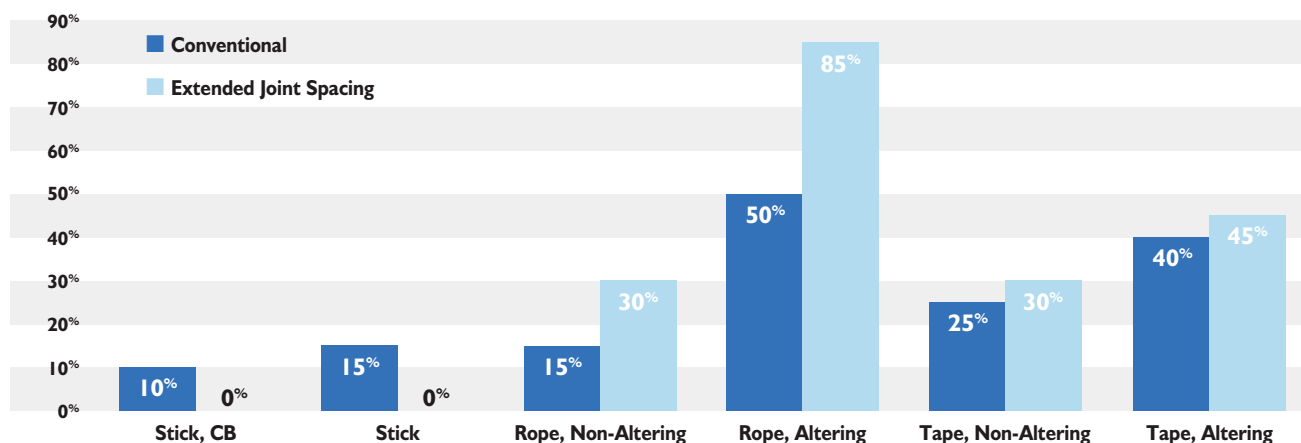


Figure 4. Increase in plastic viscosity by macrosynthetic fiber type

As can be seen from the figures, there are substantial differences between the macrosynthetic fibers with respect to the relative increases in HRWRA dosage and plastic viscosity. The differences appear to be primarily driven by the post-mix denier of each fiber. An increase in the required HRWRA dosage will result in a mixture cost increase. It should be noted that if water, rather than HRWRA, is used to offset the decrease in slump, the water addition and, therefore, the resulting reduction in compressive strength will most likely also vary by fiber type. A reduction in compressive strength can also increase the overall mixture cost if measures are taken to compensate for the strength loss.

In these evaluations, the slump was held constant through additional HRWRA; however, the plastic viscosity increased to varying degrees depending on fiber type. Generally speaking, as the plastic viscosity of concrete increases, placement and consolidation operations become more labor intensive. To overcome this upward shift in plastic viscosity, adjustments to the mixture proportions would be necessary, some of which would increase overall mixture cost. In addition to the plastic viscosity of the mixture, the final finish aesthetics (either vertical or horizontal) will depend on the fiber type, fiber dosage, mixture proportions and the placement/consolidation/finishing techniques or form surfaces used.

Conclusions

All macrosynthetic fibers are not created equal and their effects on the fresh and post-crack properties of hardened concrete will vary depending on the type used. The effect of a fiber on the rheological properties of a concrete mixture can influence placement, consolidation and finishing operations and the final finish of a concrete surface. Therefore, fibers should be evaluated for their effects on both fresh and hardened concrete properties to assess their overall influence on mixture cost as well as the desired finish and in-place cost for the intended application.

References

1. ACI 544.3R, "Guide for Specifying, Proportioning, and Production of Fiber-Reinforced Concrete", American Concrete Institute.
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3. ACI 544.1R, "Report on Fiber Reinforced Concrete", American Concrete Institute.
4. ACI 238.1R, "Report on Measurements of Workability and Rheology of Fresh Concrete", American Concrete Institute.
5. NISTIR 6819, "Comparison of Concrete Rheometers: International Tests at LCPC (Nantes, France) in October, 2000", National Institute of Standards and Technology (NIST), USA.

About Master Builders Solutions

Master Builders Solutions is a leading global manufacturer of concrete admixtures, as well as other sustainable solutions for the construction industry, focussed on delivering its vision: **Inspiring people to build better**. Master Builders Solutions provides value-added technology and market-leading R&D capabilities to improve the performance of

construction materials and to enable the reduction of CO₂ emissions in the production of concrete. Founded in 1909, Master Builders Solutions has ca. 1600 employees operating 35 production sites globally, supporting their customers in mastering their building challenges of today – for a decarbonised future.

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