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Advancements in concrete reinforcement: moving beyond hook-end fibres to twisted steel fibre

Recent advancements in fibre technology aim to extend the benefits of fibres into the pre-crack phase. A new class of reinforcement, twisted steel fibre (TSF) reinforcement, has emerged as an alternative to traditional hook-end fibres. These twisted fibres are designed to engage the concrete matrix more effectively both before and after cracking. Here, the authors introduce a 52 × 0.8mm TSF and discuss its unique mechanisms and performance benefits – including increased modulus of rupture (MOR), improved post-crack ductility as compared with popular hook-ended products and the potential for reduced member thickness and lower global warming potential (GWP) of concrete elements. These improvements enable more efficient designs such as thinner, lighter slabs and more durable tunnel linings (Figure 1), introducing the TSF as a new option for fibre-reinforced concrete in both the EU and US markets.

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Steel-fibre reinforcement has been used for decades to save time and money in a range of concrete applications – from slabs-on-grade to precast segmental tunnel linings. Design and specification of fibres traditionally focus on post-crack performance, using standardised beam tests (ASTM C1609⁽¹⁾ in the US and EN 14651⁽²⁾ in Europe) to ensure ductility and toughness after cracking. Typical performance specifications for fibre-reinforced concrete are given in terms of residual flexural strength or equivalent bending stress at certain deflections (eg, $f_{R,1}$ at 0.5mm crack mouth opening and $f_{R,4}$ at 3.5mm under

EN 14651, or ratios like $R_{e,3}$ in ASTM C1609). MOR – the nominal flexural strength at first crack – is generally not expected to increase with fibre addition according to most design guidelines. Instead, conventional fibres (typically steel fibres with hooked ends or macro-synthetic fibres) are assumed to contribute only after the concrete has cracked, by bridging cracks and providing residual strength⁽³⁾.

Design and mechanism

TSF at 0.80mm equivalent diameter and 52mm length optimised for both pre-crack and post-crack performance



Figure 1 – East Side Access Tunnel (New York, USA) precast concrete lining segments using twisted steel fibres [Helix 8-52]⁽⁹⁾.

[Photo: Richard Levine/Alamy Live News]

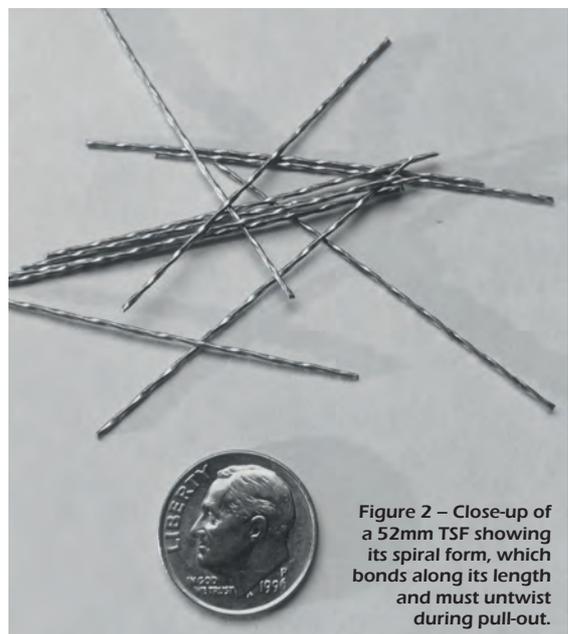
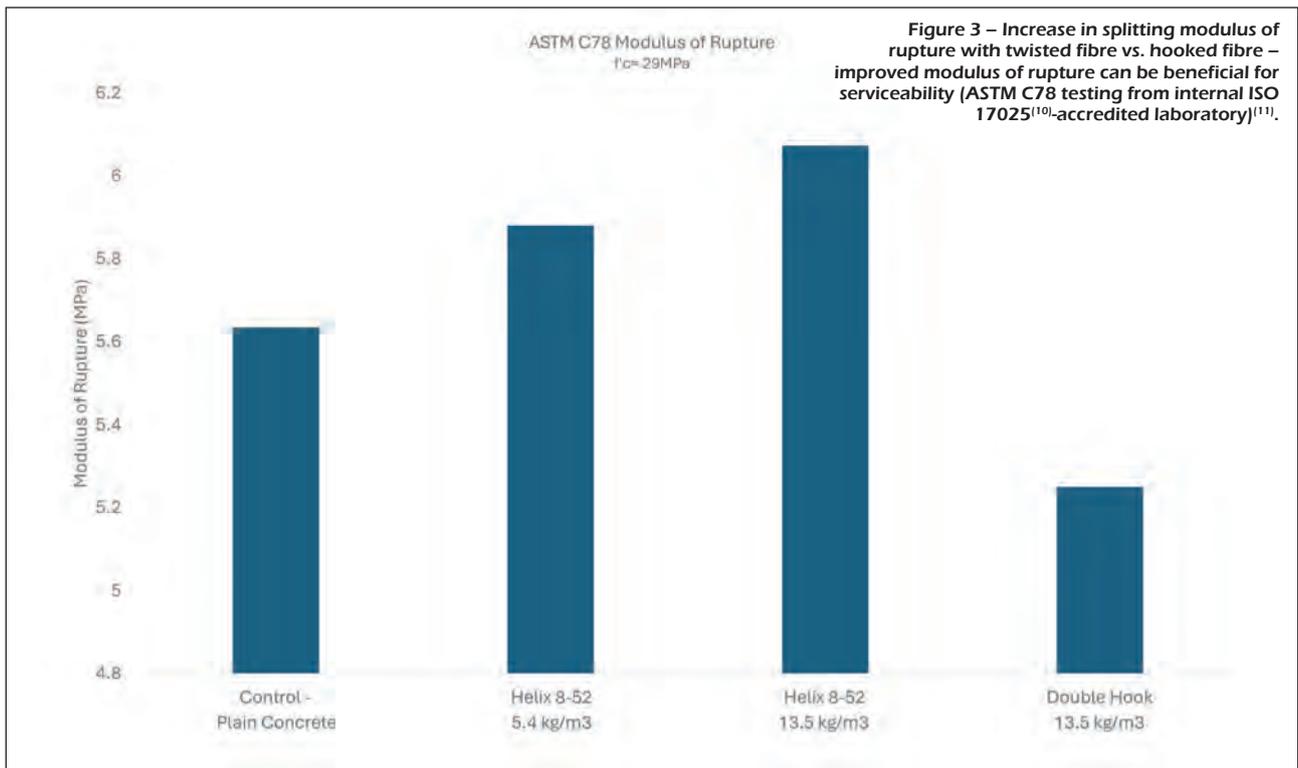


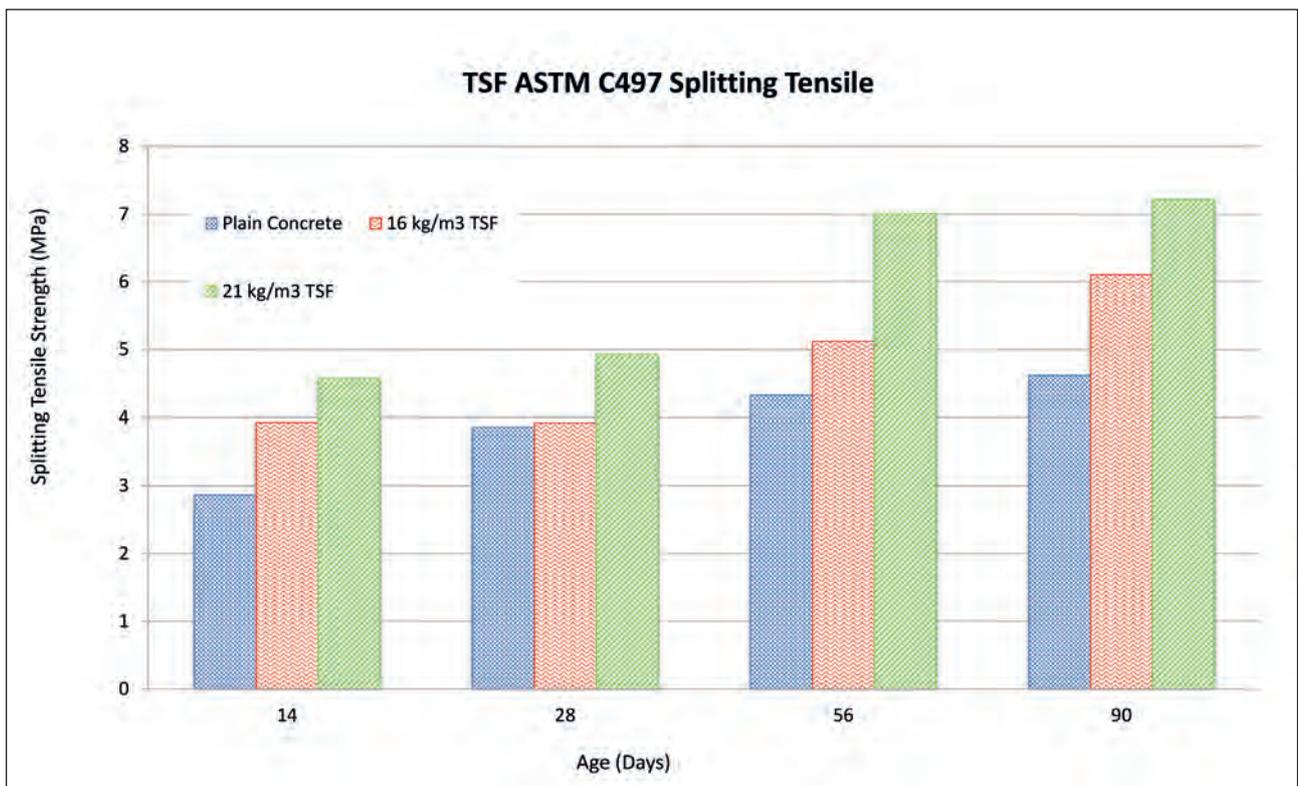
Figure 2 – Close-up of a 52mm TSF showing its spiral form, which bonds along its length and must untwist during pull-out.



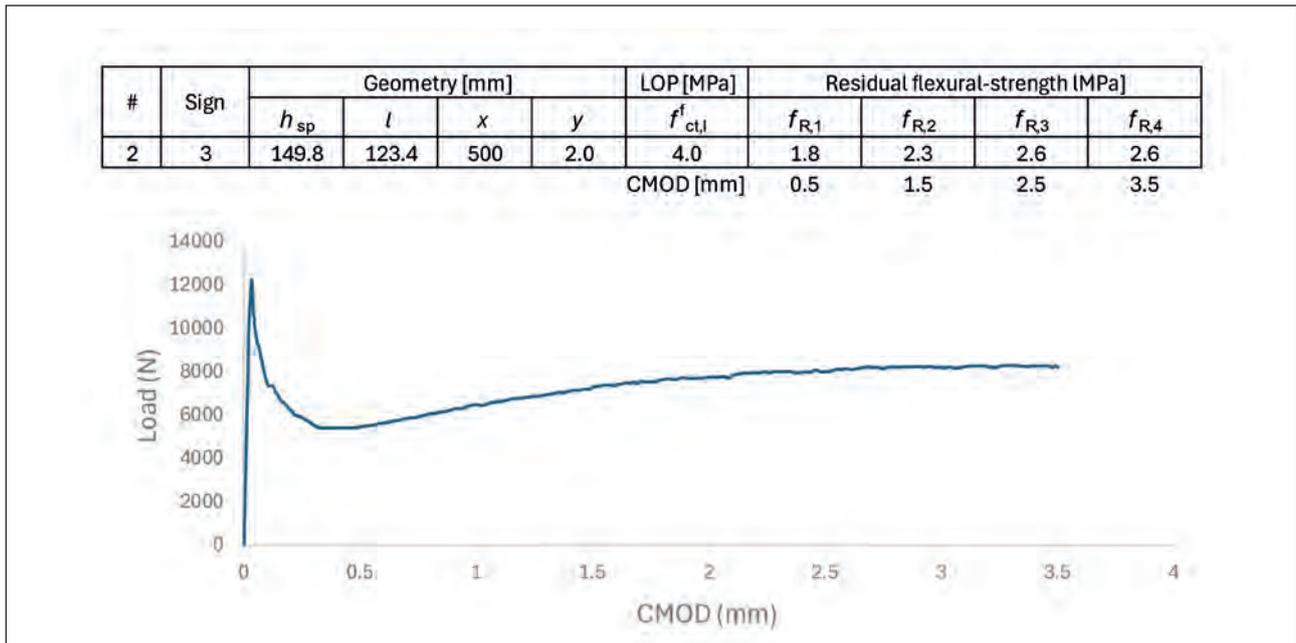
is now available in the European market with CE declaration of conformity (Figure 2). It is made from high-tensile, cold-drawn steel wire shaped into a polygonal cross-section with a continuous twist along its length. This twisted geometry distinguishes it from conventional fibres that have straight or hooked ends. Unlike a traditional steel fibre that resembles a hair grip – essentially a straight or slightly hooked segment – this design adopts a screw-like

or helical form.

The twisted profile serves a dual purpose in reinforcing concrete: a) it bonds along the fibre's entire length; and b) it introduces mechanical anchorage that requires the fibre to untwist during pull-out. In other words, as a crack opens and tries to pull the fibre out, the fibre must spiral out of the concrete like a corkscrew, dissipating energy. This mechanism is fundamentally different from that of



Above: Figure 4 – Increase in splitting tensile strength over time for concrete with twisted fibre at 15 and 21kg/m³ vs Plain concrete (control) – showing continued strength gain with twisted fibre and no age embrittlement (ASTM C497 testing at third-party ISO 17025-accredited laboratory).



Above: Figure 5 – Load vs CMOD curve from EN 14651 beam test at 10kg/m³ Helix 8-52 – demonstrating stable post-crack residual strength up to wide crack openings (EN 14651 testing at laboratory accredited under NAH-1-1902/2022).

traditional hook-end fibres, where resistance comes largely from friction and the hook pulling against the concrete (analogous to a nail with a bent end). By contrast, the twisted fibre’s anchorage is distributed and engages the surrounding concrete more uniformly.

Performance advantages of twisted fibres
Increased MOR and tensile strength

A unique advantage of TSF is its demonstrated ability to increase the MOR as measured by ASTM C78⁽⁴⁾. Generally, adding fibres to concrete does not raise the first-crack flexural strength; design Codes typically assume MOR depends only on the concrete’s compressive strength and ignore any fibre contribution. However, tests with Helix TSF have shown a statistically significant increase in MOR compared with plain concrete. In one study, Helix TSF increased MOR by approximately 10–20% at practical dosages, whereas an equivalent dosage of hook-end fibres showed a negligible change in MOR (Figure 3).

This improvement is attributed to the fibre’s ability to engage micro-cracks from the onset due to the bond and twist mechanism, effectively delaying crack initiation and propagation. An increase in MOR means that TSF-reinforced sections can withstand higher stress before cracking, which can be beneficial in serviceability (eg, reduced crack widths under working loads) and even allow for thinner sections in design before first crack occurs.

In addition to enhancing flexural strength, TSF has been observed to improve splitting tensile strength over time, as measured by tests such as ASTM C496/C496M⁽⁵⁾. Unlike some conventional steel fibres that may experience age-related embrittlement – where fibres are increasingly prone to rupture rather than pull-out as concrete matures – TSF does not exhibit this degradation. In fact, test data show that concrete reinforced with TSF continues to gain splitting tensile strength with age (Figure 4). Importantly, the failure mode remains a ductile pull-out through

untwisting, rather than shifting toward brittle fibre fracture.

Post-crack ductility and toughness

The primary purpose of any fibre reinforcement is to carry load after the concrete cracks and here TSF also shows strong performance. Flexural beam tests (notched beam tests) in accordance with EN 14651 have demonstrated that at a dosage of 10kg/m³, 0.8 x 52mm TSF fibres provide very stable post-crack behaviour, even at large crack openings. In practical terms, this means the residual load capacity does not drop off sharply as the crack widens; the fibre network continues to hold the crack faces together up to deflections of 3.5mm and beyond. Figure 5 illustrates a typical load–CMOD (crack mouth opening displacement) curve for a concrete beam with 10kg/m³ of TSF after the initial crack; the load is largely maintained or gradually reduced with increasing crack width.

Environmental and sustainability considerations

One direct way these improvements translate into field applications is by enabling thinner concrete elements for a given load capacity, thereby reducing material use and the structure’s GWP. To illustrate, consider a slab-on-grade design following the Concrete Society Technical Report 34⁽⁶⁾ method, targeting a certain load-bearing capacity. A comparative design study was performed for three cases: unreinforced plain concrete, concrete reinforced with a typical long hook-end fibre (single-hook, 60mm length) and concrete with 0.8 x 52mm twisted fibres. Each design was optimised to meet the same performance criteria (in terms of flexural strength and serviceability). The results were as follows:

- Plain concrete: Required ~650mm slab thickness (no fibres) to meet the load, resulting in high concrete volume. GWP of the concrete (cement production, etc) is approximately 220kgCO₂/m² for this design.
- With 60mm single-hook fibres: Using fibres (eg, 15kg/m³

of a single-hook fibre) improves post-crack performance, allowing a thinner slab of about 400mm thickness. The embodied carbon is reduced to approximately 140kgCO₂/m² of slab. However, this fibre dosage is relatively high.

- With 0.8 x 52mm TSF: Due to the higher flexural strength and toughness, only 10kg/m³ of TSF was needed to achieve the same (in fact, slightly better) performance, enabling a slab thickness of about 350mm. This thinner slab uses less concrete and fewer fibres. The calculated GWP is roughly 123kgCO₂/m², the lowest of all three cases (assumes ~1.3 kgCO₂/kg carbon footprint).

This comparison highlights that the TSF design met the requirements with a 50mm thinner slab (an additional ~12.5% reduction in thickness) compared with the hook-fibre-reinforced slab, and with one-third less fibre dosage. The lower concrete volume and the use of low-carbon steel fibres together significantly reduce the GWP per square metre of slab. In sustainability terms, specifying twisted fibre reinforcement can help projects achieve lower embodied carbon, contributing to greener construction practices. Hook fibre values are taken from CE public declarations of conformity and EPDs.

Performance in precast tunnel segments

Long, slender steel fibres (50–60mm length) are often used in precast tunnel lining segments to provide the required toughness and to control cracking under concentrated loads. TSF has been evaluated in this demanding application as well. Full-scale trial batches and segment castings were conducted at a precast facility (Forterra CSI in Ohio, USA) to ensure the fibres could be successfully integrated at higher dosages sometimes needed for tunnel segments (eg, 27kg/m³ and up to 42kg/m³, which is the required TSF dosage range to meet common tunnel segment specifications). Figure 6 shows several of the cast tunnel segments produced during this trial. The twisted fibres showed good dispersibility in the concrete with standard mixers and did not disrupt the production process. Even at these elevated dosages, no significant fibre balling or pumping issues were observed – an important practical consideration for segment fabrication.

The implication for tunnel design is significant. Engineers can potentially reduce fibre dosage or increase segment durability by switching to twisted fibres. With TSF, achieving the residual strength criteria of industry Standards (such as the ITAtech guidelines⁽⁷⁾ or EFNARC⁽⁸⁾ for precast segments) is possible with fewer fibres, simplifying quality control and possibly enabling thinner segment designs or elimination of some conventional reinforcing bar. Additionally, the absence of age embrittlement provides confidence in long-term performance: even many years after installation, the fibre-reinforced segments should retain their toughness and crack-control capability, enhancing the durability of the tunnel lining.

Concluding remarks

The introduction of 0.8 x 52mm TSF represents a continued evolution in fibre-reinforced concrete technology. Developed as a longer alternative to the

established 0.5 x 25mm TSF, this product is intended for structural applications where increased fibre length and performance are required. It offers a potential substitute for conventional single-hook and double-hook steel fibres, particularly in use cases where enhanced mechanical interlock or post-crack performance is desirable.

Preliminary structural applications, including segmental tunnel linings, floor slabs and precast elements, indicate that the use of TSF can enable reductions in concrete thickness and conventional reinforcement while still satisfying design and Code-based performance requirements. These optimisations may contribute to reductions in material use and overall element weight, which are of interest in both cost-sensitive and sustainability-driven projects.

In terms of constructability, the ability to achieve required performance at comparatively lower fibre dosages may improve aspects of fresh concrete behaviour. Observations from trial placements suggest improved consistence and finishability compared with higher-dose applications of shorter or hooked fibres. The risk of mixing or pumping issues, such as fibre clumping or blockage, also appears reduced at these lower dosages, though this is dependent on equipment and mix design.

Overall, the TSF expands the range of options available to designers and contractors working with fibre-reinforced concrete. Its performance characteristics – particularly with respect to both peak and residual tensile strength – support its consideration in applications where improved ductility, crack control or material efficiency are design objectives. As interest in sustainable construction practices continues to grow in the US, EU and other regions, reinforcement strategies that enable reductions in concrete volume or steel content may have increasing relevance. ■

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