The following comments relate to the paper and presentation carried out at the recent Australasian Tunnelling Conference in Sydney; *'Age-dependant Changes in Post-cracking Performance of fibre-reinforced Concrete for Tunnel Segments – by ES Bernard'.*

The underlying message from the presentation was a shameless attempt to promote plastic fibres as a suitable alternative to steel fibre reinforced concrete (SFRC). This was achieved by describing the phenomenon of fibres *rupturing* rather than deforming and slowly pulling through. Matching the correct fibre (anchorage, wire tensile strength and dosage) to suit the expected concrete strength is common practice. This is not new.

It seems the scientific community are not convinced by this propaganda, just this month two articles have been published in the *Tunnelling Journal*[1] *and tunnel talk*[2], which give a firsthand perspective of recent papers presented by S Bernard at a shotcrete conference in Norway and Brazil. They make for interesting reading.

"*Bernard calls this phenomena embrittlement, though some may find this term confusing*, explained, Dr Benoit Jones, *because this term is usually used for materials experiencing chemical changes due to aging and it is sounds as though the fibre itself is becoming more brittle, which is not the case, it is the fibre reinforced concrete as a composite material that is becoming more brittle due to high strength*"

Consequently, an increase in the structural instability described above is not due to the change of fibre reinforcement mechanics in the crack (breakage rather than pulling out) but rather to the fact that the percentage and type of fibres used is less and less appropriate as the fragility of the concrete increases.

"In fact, if we know steel fiber-reinforced concretes, we know that we should always choose a fiber geometry relative to the compactness of the matrix, as characterized by its compression resistance, in order to avoid rupture of the fiber when the matrix cracks." As explained by Pierre Rossi in a recent paper edited by Tunnel talk this month raising several points of theoretical inaccuracy and technical appreciation concern about S. Bernard's publication.

What has happened over the past few years in precast tunnel segment projects is that there has been a significant increase in actual concrete strength vs. design strength for some projects (this increase in strength can be attributed to durability demands, earlier de-moulding, etc).

The author is being a bit mischievous by suggesting Dramix RC-65/60-BN was used in the testing because *'it has and continues to be widely used in tunnel segments'*; this fibre has not been promoted into segment projects in Australasia for many years in this type of concrete. For the simple reason it is not optimised for the higher concrete strengths now being used. He doesn't understand the difference between friction and bond and he doesn't understand that ALL types of reinforcement, fibres or conventional, rely on bond and anchorage for their performance.

The results presented pay no relation to the Dramix fibre types currently being used in tunnelling projects with high concrete strengths. Development of these fibres includes testing them in a range of concrete strengths exceeding what would be expected at 28 days.

The next generation of steel fibres take this one step further, where with full anchorage the pull out mechanism is replaced by fibre elongation. This is only possible through using a high tensile (>2300MPa) ductile wire, creating previously unseen levels of performance.

The author tries to brush over the fact SFRC performs exceptionally well (even in this biased test programme...) at small crack widths, arguably the most important design consideration for precast segments. Plastic fibres on the other hand tend to pick up load later than steel, at wider crack widths, in excess of what would normally be acceptable for civil structures. Importantly, plastic fibres exhibit creep under sustained load, i.e. residual strength values obtained in a beam test cannot at this stage be used in the design of structural applications. A structural application is where constitutive laws using post crack residual strength provided by the FRC are used to design for SLS and/or ULS.

For structural use, a minimum mechanical performance of FRC must be guaranteed.

This is well documented and is the main reason fibre materials with a Young's Modulus which is significantly affected by time and/or temperature are at this stage not covered by design rules / Standards for fibre reinforced concrete (FRC), such as; NZS3101, DR AS5100, DIN 1045, Fib Model Code – to name a few. On the other hand, these rules have been perfectly validated for steel fibres.

In addition to this, there should be a minimum level of performance achievable with FRC before it can be considered as a structural material.

The Fib Model Code suggests the following: $f_{R1,k} / f_{L,k} > 0.4$ (characteristic post crack strength at small crack widths should be > 40pc of the characteristic first crack strength):

Based on the authors own results, assuming 0.75mm mentioned and working out a characteristic value based on the sample size and COV of 20pc – all the plastic fibre samples in all the concrete strengths are <0.4. This means that the minimum performance required for structural use is not achieved.

The development of design Standards for engineers combined with suitable quality control and higher performing SFRC encourage innovation and helps to provide engineers with the tools and confidence to design more economic, durable and robust solutions using this exciting material.

Benoit de Rivaz

Further reference papers:

1. Tunnelling Journal – Sept 2014.

2. TunnelTech – Sept 2014. Rossi – critique of FRS paper.

Bekaert Maccaferri Underground Solutions BVBA
SkylinE40 - Korte Keppestraat 21/02 - 9320 Aalst-Erembodegem - Belgium
BTW BE0561.750.457 RPR Aalst - IBAN: BE58 7360 0781 0079 - Swift: KREDBEBB

contact@bm-underground.com
www.bm-underground.com
T +32 53 43 10 10 - F + 32 53 43 10 19