The Use of Macro-Synthetic Fiber-Reinforced Shotcrete in Australia

by Matthew J. K. Clements and E. Stefan Bernard

Macro-synthetic fiber-reinforced shotcrete (SnFRS) has rapidly gained popularity in Australia over the past 5 years. This can be attributed mainly to the huge improvement in post-crack performance that has been demonstrated over recent years and the almost universal adoption of this material for ground support by the underground mining industry.

The properties promoted by the use of macro-synthetic fibers in shotcrete include:

- high post-crack energy absorption;
- durability after cracking;
- light weight delivery and dosing of fibers; and
- possible strain-hardening behavior under deformation.

The most compelling reason, however, for using macro-synthetic fibers is that they have become cost-competitive with other forms of reinforcement such as wire mesh and steel fiber. Since 2001, the best macro-synthetic fibers have improved their energy absorption performance in shotcrete from around 250 J (measured in an ASTM C 1550 panel at 1.6 in. [40 mm] deflection) to 700 J for a 1% dose rate (15.4 lb/yd^3 [9.1 kg/m^3]), and further improvements can still be expected. Equivalent EFNARC energy absorption values are 625 to 1750 J at 1 in. (25 mm) central deflection. This compares favorably with the best steel fibers, which achieve around 500 J at 1.5 in. (40 mm) deflection at a similar cost.

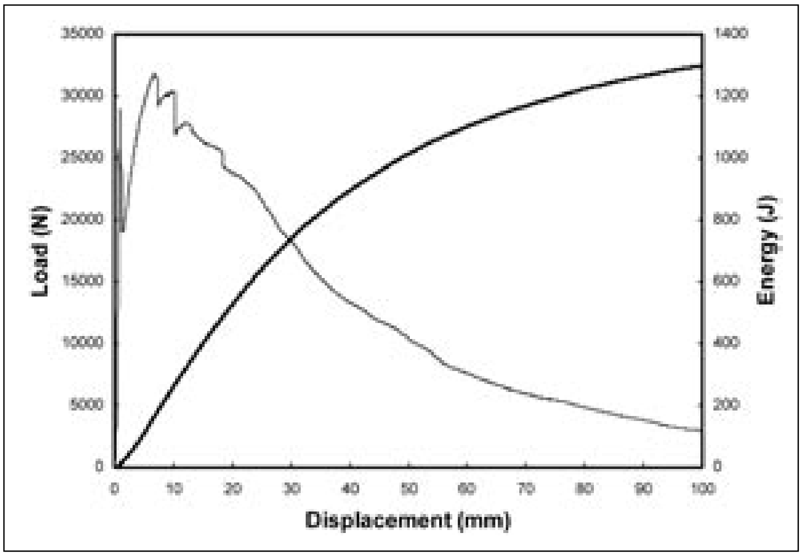

Fig. 1: Strain-hardening performance of ASTM C 1550 round FRS panels containing 20.2 lb/yd^3 (12 kg/m^3) of Barchip Xtreme fibers

Apart from cost issues, the factor that has attracted the Australian mining industry to the new macro-synthetic fiber products is the strain-hardening capabilities of the material. The round panel test (ASTM C 1550), developed in Australia, clearly shows how synthetic fibers can increase their load-carrying capacity as deformation increases from 0.04 in. (1 mm) to around 0.4 in. (10 mm) (refer to Fig. 1). This property appears to be unique to macro-synthetic fibers and is more evident in some products than others.

On the other hand, tunnel designers have thus far limited their interest in FRS performance to deformations of no more than 0.12 in. (3 mm) in beams (for example, EFNARC beams test). In this range, steel fibers perform better than macro-synthetic fibers. To date, few tunnels have embraced the new macro-synthetic fiber technology. However, designers involved with specialized civil projects, especially those projects in which there is a concern about corrosion such as water tunnels, hydro-schemes, and maritime structures, have shown a high degree of interest in this new macro-synthetic fiber technology.

Case Study—Perseverance Mine

The Perseverence Mine in Western Australia mines nickel from extensive underground deposits. The ore body rock quality is very poor and subject to high deformation during excavation (refer to Fig. 2). Keeping the mine tunnels open long enough to extract the ore is a constant challenge. WMC Resources started a project in 2003 to maximize the energy absorption of its shotcrete ground support system. The existing system consisted of spraying 3 in. (75 mm) of steel FRS (84 lb/yd^3 [50 kg/m^3] Dramix

RC65/35), installing F52 mine mesh over the full perimeter then applying another 2 in. (50 mm) of steel FRS. Deformed steel GEWI bolts were then installed in rings every 10 ft (3 m). Even with this level of support, the openings could not be maintained. The toughness of the steel FRS layer was measured at 550 J (ASTM C 1550 tested to 1.6 in. [40 mm] deflection). Deformations experienced in parts of the mine were in the order of 11.8 in. (300 mm) over a 10 ft (3 m) high wall panel, which is equivalent to a central deformation of 3 in. (75 mm) in a ASTM C 1550 panel. It was therefore decided to measure toughness up a 4 in. (100 mm) central deflection in this test—well above the standard maximum deflection of 1.6 in. (40 mm). Steel FRS panels measured 750 J of energy absorption over 4 in. (100 mm) deflection.

To gain an understanding of macro-SnFRS performance over the same range of deflection, several brands of macro-synthetic fibers were tested to 4 in. (100 mm) central deflection at the TSE laboratory in Sydney. The best macro-synthetic product tested was Barchip Xtreme, which achieved 1.6 in. (40 mm) deflection values of around 750 J and 4 in. (100 mm) deflection values of 1150 J at a dose rate of 20.2 lb/yd^3 (12 kg/m^3) (1.32% v/v). Extensive site trials of the best-performing fibers backed up the laboratory results.

Perseverance Mine has now been spraying high dose rates of 2.4 in. (60 mm) long Xtreme fiber for over 1 year. Initially, the shotcrete lining design was reduced from 5 in. (125 mm) to 3 in. (75 mm) thickness, but in the worst areas of the mine, this was unable to keep the mine tunnels open for the required time. Thicker layers and shotcrete arches are now being trialed in the worst areas. One noticeable difference in shotcrete performance underground compared to steel FRS was that the high toughness macro-SnFRS deformed with a multitude of cracks. The high-strength strain-hardening of the fibers across each crack forced the shotcrete to crack elsewhere. The resulting profusion of cracks concluded in very high levels of energy absorption. By contrast, the steel FRS tended to display a single dominant crack that then widens to failure. This aspect of performance was predicted from observations of ASTM C 1550 panel tests in the laboratory (refer to Fig. 3).

Fig. 2: High deformations are experienced at Perseverance Mine

Fig. 3: Strain-hardening post-crack behavior of FRS ASTM C 1550 round panel containing 20.2 lb/yd^3 (12 kg/m^3) of Barchip Xtreme fiber showing the development of multiple cracks as a result of very effective redistribution of load. Normally, only three radial cracks form in this test

Ongoing development trials at Perseverance Mine have further increased the performance of the macro-SnFRS as outlined in Table 1.

Table 1: Summary of development site trials ASTM C 1550 test results

Fiber	Length	Dose		Energy, J	
	(in.)/(mm)	(lb/yd^3)/(kg/m^3)	Vol %	40 mm	100 mm
Barchip Xtreme	2.8/72	20.2/12	1.32	799	1298
Synmix 55	2.2/55	20.2/12	1.32	580	1062
Synmix 75	3.0/75	20.2/12	1.32	584	1063
Dramix RC65/35	1.4/35	87.6/52	0.62	522	623

The future of macro-synthetic fibers looks bright if technological enhancements continue at the current rate of progress. If manufacturers can improve their materials in areas such as crack control, the use of macro-synthetic fibers could become as widespread as concrete reinforcement. In the meantime, shotcrete is leading the way.

References

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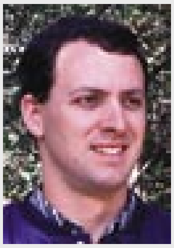

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