Use of Fiber-Reinforced Shotcrete

by Peter C. Tatnall

To paraphrase David Jamieson in his Technical Tip in the Summer 2004 issue of *Shotcrete* (page 26), as one who promotes determining the job to be done before choosing the product, I believe that the success of any fiber-reinforced shotcrete (FRS) project also depends in part on matching the appropriate fiber to the final results desired or required. It may even be possible (although I seldom admit it) that FRS is not the appropriate solution in some applications. This article discusses some of the issues to be concerned with, and provides some tips for making life a little easier when using FRS.

As many of you *Shotcrete* readers know, there have been many articles published here on FRS, and many more where FRS is mentioned. Two articles in the premier issue of *Shotcrete* in February, 1999, mentioned FRS. I have been keeping a bibliography of *Shotcrete* articles on FRS and, through Summer 2004, I have over 20 listed. These, of course, are available on the American Shotcrete Association (ASA) website. For example, in an editorial in the May 2000 issue, Mike Ballou says, "Steel Fiber Reinforced Concrete—It is time to find out about it," and in a Spring 2003 Technical Tip, Denis O'Donnell discusses where fibers should or should not be used in ground support for hard rock mining.

In applications where ACI 318 structural reinforcing is not required, fibers are an alternative means of reinforcing shotcrete. We all know how difficult it is to ensure full encasement of conventional reinforcement—bars or mesh. This concern is eliminated with the use of fibers. In many ground support applications, above and below ground, it can be costly and difficult to pin mesh. Typically, mesh spans from high spot to high spot and requires much more shotcrete to fill deeper sections while trying to encase and provide proper cover to the mesh, rather than simply following the contours of the ground as can be done with FRS. In many projects, micro-synthetic fibers can provide plastic shrinkage cracking control for problematic curing conditions. In ground support projects with large deformations, perhaps the newer macro-synthetic fibers are an appropriate alternative, providing increasing load capacity with increasing deformations.

In any of these uses of fibers, the shotcrete contractor must take into account a few basic issues:

- Fibers must be thoroughly mixed into the shotcrete mixture. Whether added at the batch plant or at the project site, proper mixing is required. After 12 years in the ready mix business, I now recommend mixing for at least 40 revolutions at mixing speed when anything is added to a truck mixer. Some fibers may take a little more mixing. Fibers added within the batch plant normally do not require extra mixing;
- While proper combined aggregate grading is important for any shotcrete mixture, for FRS mixtures with macro-fibers, it can be doubly important. If grading is "gapped," deficient in material retained on a sieve or two, then the probability of causing plugs in the pump line increases. This is always true for nonfibrous shotcrete or concrete as well, but FRS fibers can be easily pushed out of the matrix, making the problem even worse. In some cases, I have been able to correct the problem by adding an air-entraining admixture (AEA). Adding AEA to achieve 8 to 10% air at the pump has helped when the mixture lacked fine aggregate particles. As demonstrated on many occasions, the air content in place will be in the 3 to 5% range no matter how much air we have at the pump, within reason. A good guide to the combined aggregate grading required is found in ASTM C 1436;[1]

Table 1: Grading limits for combined aggregate for shotcrete[1]

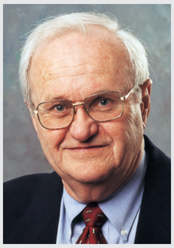
Percent by mass passing individual sieve		
Sieve size, U.S. standard	Grading, No. 1	Grading, No. 2
12.5 mm (1/2 in.)	—	100
9.5 mm (3/8 in.)	100	90 to 100
4.75 mm (No. 4)	95 to 100	70 to 85
2.36 mm (No. 8)	80 to 98	50 to 70
1.18 mm (No. 16)	50 to 85	35 to 55
600 µm (No. 30)	25 to 60	20 to 35
300 µm (No. 50)	10 to 30	8 to 20
150 µm (No. 100)	2 to 10	2 to 10

- Sometimes getting FRS to flow through grates on pumps or slick lines can be a problem. Removing the grate is not the answer as it is unsafe. Also, a large object inadvertently dropped into the hopper may damage the pump or plug the lines. The use of an elongated grate, with rectangular openings, say 1-1/2 x 3 in. (38 x 76 mm) will help facilitate FRS flowing through the grate. Mechanical vibrators have also been mounted on the grates to assist flow;
- Micro-synthetic fibers are used, up to about 4 lb/yd^3 (2.5 kg/m^3) to provide plastic shrinkage cracking control, some enhancement to sloughing resistance, synergistic behavior with macro-fibers, and for explosive spalling protection in shotcrete exposed to fire;
- Macro-fibers are used where post-cracking load capacity is required. Steel fibers are typically used when cracks must be held tightly together. Synthetic fibers are used where very large deformations are expected;
- Fibers, both steel and synthetic, do not corrode within the shotcrete mass. Therefore, durability concerns in tough environments are alleviated. Steel fibers exposed to the atmosphere will corrode, but will not spall the concrete because the mass of the fiber is not great enough to cause excessive spalling pressures. Steel fibers will not corrode below the carbonation depth, a few millimeters into the surface; and
- The use of synthetic fibers in dry-mix shotcrete is probably not a good idea because the fibers tend to blow away in the shotcrete stream. Some contractors do use steel fibers with the dry process successfully, but I always recommend pre-dampening prior to shooting to reduce overall rebound and fiber rebound.

I hope some of these tips prove useful. Most of the major fiber suppliers should be able to give you tips for shotcreting specific for their fibers. If not, e-mail me at pete_tatnall@sind.com.

References

1. ASTM C 1436, "Standard Specification for Materials for Shotcrete," *ASTM Annual Book of Standards,* V. 04.02, ASTM International, West Conshohocken, PA; www.astm.org.



Peter C. Tatnall, *Director of Underground Construction, SI Concrete Systems, is a founding member and Past President of ASA. He is a Fellow of ACI and serves as Chair of ACI Committee 506, Shotcreting. Tatnall is also an Honorary Member of ASTM International Committee C09, Concrete and Concrete Aggregates, and serves as Chair of Subcommittee C09.46, Shotcrete. He also is a member of the American Society of Civil Engineers (ASCE) and the American Underground Construction Association (AUA).*