Shotcrete Reinforcement

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Before the 1970s, shotcrete was reinforced either with conventional reinforcing steel welded wire mesh fabric, or in some instances with chain-link mesh or even chicken mesh. In the early 1970s the concept of steel fiber reinforced shotcrete (SFRS) was developed by David Lankard at the Battelle Laboratories in Columbus, Ohio. The first practical application of SFRS in the USA was for lining a tunnel adit at Ririe Dam, Idaho in 1973 (1). In Canada the first practical application of SFRS was conducted by the writer in 1977 and was for stabilization of a sloughing railway embankment in Burnaby, British Columbia. Figure 1 shows a historic picture of this work being done using dry-bagged materials and the dry-mix shotcrete process. In the quarter century since these early pioneering projects, SFRS has developed from a research curiosity into a major construction method. Many hundreds of thousands of cubic meters of SFRS are applied each year in a wide range of civil engineering and mining applications in most of the world's industrialized nations. Major civil engineering uses of SFRS include primary and final linings in road, rail, water conveyance, and other tunnels; underground support in hydroelectric power plants, sports complexes and military installations; slope stabilization and lining of channels and other water conveyance/retaining structures.

The first use of synthetic fibers in shotcrete was in research work conducted in Europe in 1968, using polypropylene fibers. There was some limited use of collated fibrillated polypropylene fibers at low fiber addition rates (0.1% to 0.2% volume) in shotcrete in North America in the 1970s and 1980s. At these low fiber addition rates, the effect on shotcrete toughness was minimal and benefits were mainly limited to control of plastic shrinkage cracking and providing the shotcrete with enhanced green strength for carving and finishing. In the late 1980s, work was done with collated fibrillated polypropylene fibers added to wet-mix shotcretes at addition rates around 0.5% volume. At these addition rates the shotcretes displayed enhanced toughness and impact resistance. There was some use of such shotcretes in environmental and infrastructure rehabilitation projects (2).

Major strides in the use of synthetic fibers in wet-mix shotcrete have, however, taken place in the 1990s. New generation fibers, typically monofilament synthetic fibers, capable of addition to wet-mix shotcretes at 1.0 to 1.5% volume (and in some cases even up to 2.0% volume) have now been developed and used in a variety of slope stabilization, underground support, and infrastructure rehabilitation projects (2). A large industry-sponsored study has just been completed by the writer's company in which the behavior of plain, mesh-reinforced, steel fiber reinforced and synthetic fiber reinforced shotcretes has been compared. Tests conducted include the ASTM C1018 flexural toughness test on beams and tests on large panels, modeled after work done by Kirsten for the mining industry in South Africa (3). In this test, a large 1.6 x 1.6 m x 80 mm (5 ft. 3 in. x 5 ft. 3 in. x 3 in.) thick shotcrete panel, with rockbolts at 1.0 m (3 ft. 4 in.) centers is load tested to destruction (150 mm/5.6 in. end point deflection) using a uniformly distributed load applied by a water bag. The load versus deflection response is recorded together with mapping of the crack pattern and crack width versus deflection. Figure 2 shows a steel fiber reinforced shotcrete panel at 150 mm deflection. These tests (4) have demonstrated that the new generation high volume synthetic fibers can provide equivalent or even superior toughness (load versus deflection response after cracking) compared to com-

Continued on p. 32

Figure 1. Stabilization of a sloughing railway embankment.

Figure 2. Steel fiber reinforced shotcrete panel at 150 mm (5.6 in.) deflection.

Shotcrete Reinforcement

Continued from p. 4

monly used mesh and steel fiber reinforced shotcretes. These new synthetic fibers appear to be particularly advantageous for use in projects such as mining applications, where the shotcrete linings may be subjected to large deformations and cracking. More details regarding this study will be provided in a future edition of ASA's *Shotcrete* magazine.

References

1. ACI 506.1 R-84, "State-of-the-Art Report on Fiber Reinforced Shotcrete," American Concrete Institute.
2. Morgan, D.R., "High Volume Synthetic Fiber Reinforced Shotcrete," First Annual Synthetic Fiber Reinforced Concrete Symposium, Orlando, Florida, January 16, 1998, pp. 115-132.
3. Kirsten, H.A.D., "Comparative Efficiency and Ultimate Strength of Mesh and Fibre Reinforced Shotcrete as Determined from Full-Scale Bending Tests," *Journal, South African Institute of Mining and Metallurgy*, Vol. 92, No. 11/12, Nov./Dec., 1992 pp. 303-323.
4. Morgan, D.R., Heere, R., McAskill, N. and Chan, C., "System Ductility of Mesh and Fibre Reinforced Shotcretes," ACI Seminar, New Developments in Shotcrete, ACI Chicago, March 17, 1999.