Fibrous concrete's potential and challenges in blast-resistant construction

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Concrete has been a material of choice for blast resistance because of its mass, which is a fundamental requirement for blast resistance. In dynamic applications, concrete is handicapped by its brittle nature, so it is commonly modified for ductility by incorporating steel reinforcement.

Some structural engineers realize the potential in using fibers for blast resistance, but fiber reinforcement is a specialized technology and attempts at adopting fibers have not achieved widespread success in this application. This article discusses some of the opportunities and challenges associated with using fibrous concrete for blast-resistant construction.

Composite concrete structures with high steel content generally behave satisfactorily and are considered the state of the art for blast resistance. The single, notable drawback for the behavior of reinforced concrete in blast events is the spalling that occurs, which is hazardous to human safety. Using fibers is a potential solution to the spalling problem, but their use has been limited because it is considered specialized technology.

To date, research of fibrous concrete has shown that a small volume proportion of fibers can significantly increase impact resistance,[1] and early military field testing demonstrated its demolition resistance to impact tools. In the past 40 years, concrete technology has improved to the point that fiber-volume proportions that were unattainable during the earliest research are now achievable. To put this in perspective, common applications of fiber reinforcement in practice use fiber-addition rates up to 1% by volume, whereas blast-resistant enhancement requires proportions from 2% to 10%.

Blast testing of fibrous concrete

Almost all testing for blast resistance is conducted by exposing specimens to a given explosive charge and comparing the behavior of the test specimen to that of a control specimen. Specimen performance was evaluated based on the number of cracks and the area of cracking, as well as material displacement measures. In each instance, the fiber-reinforced concrete specimen was superior to the unreinforced specimen.

It is encouraging to learn what the U.S. Army Engineer Research and Development Center has done in this area. A presentation by Reed Mosher[2] revealed the acceptance of fiber reinforcement as a required element of very high-strength concrete (VHSC). The Army research has further determined that coarse aggregate is undesirable for optimum performance and fiber reinforcement must be scaled to perform at meso, micro, and nano levels.

Structural design for blast resistance

In static structural design, estimated material properties are factored downward to arrive at the static capacity. In dynamic structural design, the maximum apparent elemental properties are used as the dynamic capacity because of expected synergies in the system. The static design loads are limited to the yielding of the steel, whereas in the dynamic design loads it is desirable for the steel to yield. For dynamic design considerations, the materials' strain-rate sensitivity is introduced.

Current computer design models contain dynamic increase factors (DIFs) that recognize the time period for a given material to reach its yield stress. Another variable that the models use is a dynamic analysis response limit, which evolved from DIF. These models all limit concrete reinforcement to conventional steel reinforcement. The models can predict dynamic events from known materials and given explosive charges.

Structural design with fibrous concrete

Only during this decade has structural-design methodology evolved to permit static design with fibrous concrete. Applying this structural-design methodology to dynamic design is a big leap.

However, if fibrous concrete can be considered a homogenous material, there is no reason that it can't be incorporated into the current computer models for dynamic design. The challenge is to establish a table of DIFs for various fibrous concretes.

As stated previously, fiber volume proportions would range from 2% to 10%, and optimum fiber configurations would vary to accommodate the meso, micro, and nano levels of reinforcement. Regarding fiber materials, steel is commonly accepted but polymeric materials are strain hardening and can compete with steel performance at high strain rates.

Currently, fibrous concrete static properties are measured by ASTM C1609, ASTM C1550, and ASTM C1399.[3–5] ASTM C 1609 is a third-point prism-bending test that measures energy absorption throughout the elastic and post-cracking regions. ASTM C1550 is a round-panel, center-point-bending test measuring biaxial stresses on a 200 lb (0.9 kN) specimen throughout the elastic and post-cracking regions. ASTM C1399 is a third-point, prism-bending test measuring average uniaxial stress in the post-cracking region.

Any of these tests can be used to qualify fibrous concretes for dynamic applications; however, polymeric fibers would be at a disadvantage because their strain-rate hardening properties are not revealed in these tests. There are significant performance differentials in ASTM C1609, ASTM C1550, and ASTM C1399 among various commercial fibers for concretes containing less than 1% by volume. However, in high-volume-fiber (2% to 10% by volume) concretes tested for dynamic properties, the performance variability would be slight.

The initial step to incorporate fiber reinforcement into the current design models would be to establish optimized steel-fiber concretes at three or more fiber proportions in the dynamic performance range of 2% to 10% and develop a curve from which the DIFs can be determined. Polymeric and other fiber materials would follow in the process. Fibrous concrete manifests ductility in proportion to the fiber content in the composite.

To move forward

Unfortunately, current research has not progressed much further because the fiber-performance variables are largely unknown by those outside the fiber industry. Because it is very expensive for individual manufacturers to commercially fund explosive research and it is also logistically restrictive since September 11, 2001, the fiber industry should pool resources to move this technology forward.

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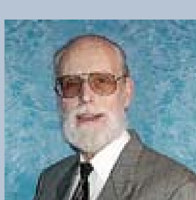

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Synopsis

Concrete is handicapped in dynamic applications by its brittle nature. Some structural engineers realize the potential in using fibers for blast resistance, but fiber reinforcement is a specialized technology and attempts at adopting fibers have not achieved widespread success in this application. This article discusses some of the opportunities and challenges associated with using fibrous concrete for blast-resistant construction.

Keywords

Blast, blast resistance, design, fiber-reinforced concrete, fibers.

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