Fibre-reinforced concrete
Beaudoin, J. J.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/40000739
Canadian Building Digest, 1982-04-01

Canadian Building Digest
Division of Building Research, National Research Council Canada

CBD-223

Fibre-Reinforced Concrete

Please note

Originally published April 1982.

J.J. Beaudoin

Concrete lends itself to a variety of innovative designs as a result of its many desirable properties. Not only can it be cast in diverse shapes; but it also possesses high compressive strength, stiffness, low thermal and electrical conductivity and low combustibility and toxicity.

Two characteristics, however, have limited its use: it is brittle and weak in tension. Recently, however the development of fibre-reinforced composites in the plastics and aerospace fields has provided a technical basis for improving these deficiencies.

This Digest describes the general properties and application of fibre-reinforced concrete used in construction. The promise of thinner and stronger elements, reduced weight and controlled cracking by simply adding a small amount of fibres is an attractive feature of fibre-reinforced concrete.

Role of Fibres

When the loads imposed on concrete approach that for failure, cracks will propagate, sometimes rapidly; fibres in concrete provide a means of arresting the crack growth. Reinforcing steel bars in concrete have: the same beneficial effect because they act as long continuous fibres. Short discontinuous fibres have the.advantage, however, of being uniformly mixed and dispersed throughout the concrete. Fibres are added to a concrete mix which normally contains cement, water and fine and coarse aggregate. Among the more common fibres used are steel, glass, asbestos and polypropylene (Table 1).

Table 1. Physical and Mechanical Properties of Selected Fibres.

Fibre	Diameter μm	Specific Gravity	Failure Srain, %	Modulus of Elasticity, GPa	Tensile Strength, GPa
Steel	5-500	7.8	3-4	200	1-3
Glass	9-15	2.6	2-3.5	80	2-3

Polypropylene	7.5	0.9	20.0	5	0.5
Mica Flakes	0.01-200	2.9	--	170	0.25
Asbestos	0.02-20	2.5-3.4	2.3	200	3
Carbon	7.5	1.7-2.0	0.5-1.0	300-400	2-3

If the modulus of elasticity of the fibre is high with respect to the modulus of elasticity of the concrete or mortar binder, the fibres help carry the load, thereby increasing the tensile strength of the material. Increases in the length:diameter ratio of the fibres usually augment the flexural strength and toughness of the concrete. The values of this ratio are usually restricted to between 100 and 200 since fibres which are too long tend to "ball" in the mix and create workability problems.

As a rule, fibres are generally randomly distributed in the concrete; however, processing the concrete so that the fibres become aligned in the direction of applied stress will result in even greater tensile or flexural strengths.

Fabrication

Before mixing the concrete, the fibre length, amount and design mix variables are adjusted to prevent the fibres from balling. Satisfactory reinforced mixes usually contain a mortar volume of about 70 per cent compared with a mortar volume of about 50 percent for typical unreinforced concrete mixes.

Fibre-reinforced cement boards contain no coarse aggregate. These products are usually made by spraying mortar and chopped fibre simultaneously. Mortar with a high water:cement ratio is used to facilitate spraying. Other application methods include simple casting, which is less versatile than spraying, and press moulding, which results in a lower effective water:cement ratio, thus producing a stronger product.

Chemical admixtures are added to fibre-reinforced concrete mixes primarily to increase the workability of the mix. In North America, air-entraining agents and water-reducing admixtures are usually added to mixes with a fine aggregate content of 50 per cent or more.

Superplasticizers[1], when added to fibre-reinforced concrete, can lower water:cement ratios, and improve the strength, volumetric stability and handling characteristics of the wet mix.

Various Applications

A proliferation of new developments in fibre-reinforced concrete technology has greatly extended the range of applications (Table 2).

Table 2. Application of Various Fibres in Cement Products*

Fibre Type	Application
Glass	Precast panels, curtain wall facings, sewer pipe, thin concrete shell roofs, wall plaster for concrete block.
Steel	Cellular concrete roofing units, pavement overlays, bridge decks, refractories,

	concrete pipe, airport runways, pressure vessels, blast-resistant structures, tunnel linings, ship-hull construction.
Popypropylene, nylon	Foundation piles, prestressed piles, facing panels, flotation units for walkways and moorings in marinas, road-patching material, heavyweight coatings for underwater pipe.
Asbestos	Sheet, pipe, boards, fireproofing and insulating materials, sewer pipes, corrugated and flat roofing sheets, wall lining.
Carbon	Corrugated units for floor construction, single and double curvature membrane structures, boat hulls, scaffold boards.
Mica Flakes	Partially replace asbestos in cement boards, concrete pipe, repair materials.

* Combinations of more than one fibre type can be used for special purposes.

Composite Properties

Fibres can improve the toughness, the flexural strength, or both, and are chosen on the basis of their availability, cost and fibre properties. For example, polypropylene fibres significantly increase concrete toughness but have little effect on tensile strength. Mixtures of polypropylene and glass fibres, on the other hand, produce concrete with a high degree of both toughness and flexural strength (see Table 3 and Table 4).

Table 3. Ratio of Toughness Values of Some Fibre-Reinforced Cementitious Materials With Respect to Unreinforced Materials.

Composite	Volume Percent (%) of Fibre	Relative Toughness*
CONCRETE		
steel	0.5	2.5-4.0
steel	1.0	4.0-5.5
steel	1.5	10-25
glass	1.0	1.7-2.0
polypropylene	0.5	1.5-2.0
polypropylene	1.0	2.0-3.5
polypropylene	1.5	3.5-15.0

MORTAR		
steel	1.3	15.0
asbestos	3-10	1.0-1.5
CEMENT PASTE		
glass	4.5	2.0-3.0
mica flakes	2.0-3.0	3.0-3.5

* These values are representative values only and may vary additionally dues to differences in test methods and specific process and mix variables.

Table 4. Ratio of Flexural Strength of Some Fibre-Reinforced Cementitious Materials With Respect to Unreinforced Materials.

Composite	Volume of Fibre (%)	Relative Flexural Strength*
CONCRETE		
steel	1-2	2.0
glass	1-2	2.5-3.5
MORTAR		
steel	1.3	1.5-1.7
glass	2	1.4-2.3
asbestos	3-10	2.0-4.0
CEMENT PASTE		
glass	4.5	1.7-2.0
mica flakes	2-4	2-2.5
polypropylene	1-2	1.0

* These values are representative values only and may vary additionally due to differences in test methods and specific process and mix variables.

Fibres also generally reduce creep strain, which is defined as the time-dependent deformation of concrete under a constant stress. For instance, steel-fibre-reinforced concrete can have tensile creep values 50 to 60 per cent of those for normal concrete. Compressive creep values, however, may be only 10 to 20 per cent of those for normal concrete.

Shrinkage of concrete, which is caused by the withdrawal of water from concrete during drying, is lessened by fibres. Shrinkage of glass-fibre-reinforced concrete is decreased by up to 35 per cent with the addition of 1.5 per cent by volume of fibres.

Other properties of concrete, such as compressive strength and modulus of elasticity, are not included in the tables since they are affected to a much lesser degree by he presence of fibres.

Long-Term Performance of Alkali-Resistant, Glass-Fibre-Reinforced Cement

Since the late 1960's, the use of alkali-resistant glass fibres for reinforcing cement has received appreciable attention because of their excellent engineering properties.[2] There has been concern, however, over possible adverse reactions between the fibres and the matrix, even though they are alkali resistant.[3,4] The values for the properties of glass-fibre composites given in Table 3 and Table 4 were obtained from samples in which the fibres had not undergone corrosion.

The tensile strength and the impact strength of glass-fibre-reinforced cement products decrease with age if exposed to outside weather.[5] This time-dependent decrease in flexural strength, first noted in alkali-resistant glass-fibre composites, has also been observed in high alumina and supersulphated cements in which only small amounts of alkali are present. Glass-fibre reinforced cement products that decrease with time in tensile and impact strength should not be used for primary structural applications. Glass fibres have been used successfully to avoid cracking problems due to shrinkage stresses in the production of thin sheet.

Most other fibres in use are relatively stable when embedded in cement. Strength decreases have not been observed in specimens containing carbon and Kevlar fibres. Combining fibre types in cement composites is a new approach with high potential for improving the long-term performance of glass-fibre-reinforced cement products. Mixtures of polypropylene and glass fibres or, alternatively, mica flakes used as fibres may help prevent long-term decreases in tensile and impact strength.

Environmental Factors

The resistance of fibre-reinforced concrete to environmental factors such as frost action depends on the quality of the concrete matrix material and should not differ substantially from that of conventional concrete. Fibres can be effective, however, in reducing frost damage because of their crack-arresting properties. Care should be taken to ensure that an adequate amount of entrained air is incorporated in the mix to provide additional resistance to freezing and salt corrosion.

Other environmental problems such as acid attack, sulphate attack and alkali-aggregate reaction are generally not augmented by the presence of fibres unless there is a chemical reaction between the fibre and the concrete.

Concluding Remarks

Innovations in engineering design, which often establish the need for new building materials, have made fibre-reinforced cements very popular. The possibility of increased tensile strength and impact resistance offers potential reductions in the weight and thickness of building components and should also cut down on damage resulting from shipping and handling.

Although ASTM C440-74a describes the use of asbestos-cement and related products, there are, at this time, no general ASTM standards for fibre-reinforced cement, mortar and concrete. Until these standards become available, it will be necessary to rely on the experience and judgement of both the designer and the fibre manufacturer. The onus is thus on the designer to be aware of the limitations presently inherent in some of these composites, particularly the durability of glass-fibre-reinforced products.

References

1. Ramachandran, V.S. Superplasticizers in concrete. National Research Council of Canada, Division of Building Research, **Canadian Building Digest 203**, February 1979.
2. Majumdar. A.J. and J.F. Ryder. Glass Fibre Reinforcement of Cement Products, Glass Technology, Vol. 9 (3), p. 78-84, 1968.
3. Majumdar. A.J. and R.W. Nurse. Glass Fibre Reinforced Cement, Materials Science and Engineering, Vol. 15, p. 107-127, 1974.
4. Cheetham, C.J. and P. Maguire. Coating of Glass Fibres, U.S. Patent 4,173,486, 1979.
5. Building Research Station. A Study of the Properties of Cem-Fil/OPC Composites, Building Research Establishment Current Paper, CP38/76, Garston, England, 1976.