

Plastic and Steel Fiber-Reinforced Concrete Applications

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ABSTRACT

The designed properties of concrete for the use of steel or plastic fiber reinforcement are discussed. The reasons for using fiber reinforcement are cited from experience and case histories at chemical plants in various locations in the United States. The implementation techniques and applications are about repairs and original work with fiber-reinforced slabs, grade beams, and equipment and tower foundations. The benefits of using fiber reinforcement were realized in scheduling, economy, ease of placement, volume constraints, fire resistance, modulus of rupture, fatigue strength, skid resistance, durability, repairability, joint spacing, and deflection control. Histories have shown savings of 10 percent or more on projects bid against alternate designs with conventional reinforcement. Superplasticizer was vital in most cases to ease placement of the steel fiber-reinforced concrete. Field changes in some cases allowed no design changes to the concrete, and the performance has been better than expected with no adverse effects. These applications have highlighted the successful uses of plastic and steel fiber-reinforced concrete. However, there are risks from the lack of material design information that challenge the normal concrete codes and practices for design.

Fiber-reinforced concrete (FRC) is considered by many to be a new and challenging composite material. However, enthusiasm for trying a new material can either subside or soar by hearing of experiences and case histories. Most articles about fibers in concrete begin with a discussion of earlier efforts using straw in mud (1). Most of those earliest details are lost, except for one. Remember that Pharaoh wanted to punish Moses by denying him straw necessary in the mud for making bricks. Even with this history, the use of fibers as reinforcement in concrete is still a new and exciting challenge and sometimes needs some defending. Examples of the enthusiasm and faith necessary for proper material applications of fiber reinforcement in concrete are imparted in this paper.

It has been suggested that the U.S. Department of Defense was the initiator of interest in fiber-reinforced concrete in the late 1950s. Regardless of the historical responsibility, most of the market from that time has consisted of individual fibers from glass and sheet steel by-products or scrap. These were commonly known as fiberglass and steel shavings. The introduction of these fibers into the concrete became a problem due to handling, balling, and uneven dispersion. The benefits in performance of the concrete were not significant enough in most cases to warrant the additional effort. Because proper design, manufacture, and construction of concrete already necessitates ample direction, the addition of fibers became just another problem to avoid.

Since 1975 the markets and applications of FRC have opened up considerably from the introduction of new technology fibers. In many cases, these fibers have displaced the old by overcoming the mix introduction problems and significantly improving performance. However, additional effort is still required for proper control. The technology has definitely not yet matured, but enough information is available for wisely choosing the proper application of FRC and then using this experience as a basis for yet further refinements.

PRODUCTS

The two fiber materials discussed in this paper are polypropylene plastic and high strength steel. Plastic fibers were available in different lengths depending on maximum aggregate size (2,3). The pre-mix fibers were collated or grouped into a bundle resembling a cigarette filter. The mechanical mixing action of the concrete unraveled this filter into a weak "hair net," which further mixing tore into individual fibers.

Steel fibers are available in different lengths depending on maximum aggregate size and design requirements (4,5). The "premix" fibers supplied by one manufacturer are available in two conditions: separate and individual fibers and those fibers collated and held together by weak glue. The availability of the fibers in these two conditions made a difference for mixability, handling, and batching operations for the job applications.

Collated fibers were chosen as much easier to handle and introduce into the mix by hand than the individual fibers. The collation and glue disappeared and the fibers were uniformly dispersed in the matrix from the mechanical shearing and mixing action of the batcher. However, some difficulty was encountered with too much glue on occasions, and balls of collated fibers were found. When these balls were broken apart or if the bag of collated fibers was shaken to ensure individual collated bundles, there were no problems with dispersion.

The single fibers were not used as they were expected to be more difficult to handle and more difficult to introduce into the mix. Single fibers have been observed to be much more prone to mechanically interlock and ball together before mix introduction (6).

The preferred way for mix addition depended on the job site conditions. The collated fibers could be added in bulk at the plant or on the site. Because some of the literature on single fibers indicates that fibers are best added by sprinkling or by a measured addition rate, this additional equipment, manpower, and scheduling problem was avoided by using collated fibers.

Fibers were introduced in two ways: (a) at the batch plant with mixing done en route and (b) at the job site with a specified time for mixing. The choice of where mixing occurred was determined by scheduling, safety, and ensuring the quality of the concrete before the fibers were introduced.

The steel fiber concrete usually had similar amounts of aggregate and sand, with a high cement content. The reason for these mix proportions was to

ensure the bonding, locking, and contact of the fibers in the concrete matrix.

No modification of the mix for workability was necessary according to both the plastic and steel fiber manufacturers. The plastic fiber manufacturers acknowledged a loss in slump due to the fiber. However, their reasoning for not modifying the mix was that the loss in slump would be 1.5 to 2.5 in. (3.8-6.4 cm) but the real loss in workability would only be about 0.5 in. (1.3 cm). The significance of this 0.5-in. (1.3-cm) difference was evidently of concern to their marketing department.

The steel fiber manufacturers also acknowledged a loss in slump but hesitated to recommend another product to cure an "ill" of their product. The usual loss in slump was about 2 to 3 in. (5 to 7.6 cm).

The project engineer's concern has been with the quality of the concrete, which, in most cases, has always been a direct function of the amount of water. Experience showed that when a finisher saw a low slump concrete, it made no difference to him whether the link between slump and workability was apparent or real, the water was usually added. For this reason, the slump and water content needed to be determined and fixed with no field adjustment allowed except by special approval. The desired slump was first obtained with the understanding that there would be a subsequent loss in slump after the fibers were introduced.

The generally accepted key to fiber performance in concrete has been bonding and dispersion in the matrix. The use of a superplasticizer easily overcame the problem of water addition by providing flow, workability, and the ensured cement dispersion in the matrix. The superplasticizer improved the bonding and performance of the fibers because of the improved contact with the other materials by easier mixing, dispersion, and less working into position. The less working into position ensured that the fibers were positioned homogeneously and were not moved out of a plane due to the insertion of a tool through the matrix. The finished plastic or steel fiber concrete appeared "hairy" from a very close examination of most applications.

PROPERTIES

As always, the mechanical performance objectives of a material needed to be cost-optimized, and fiber-reinforced concrete was no different than any other material considered in a project application.

Some properties are presented in Table 1 as a summary of comparisons between fiber-reinforced and conventional nonfiber concrete. These properties are, from application experience, supported by actual testing and field observation of performance since 1979. The exact values of these properties are cited and compared in other technical literature. However, the relative values are important in material selection.

TABLE 1 Property Comparison Index^a

| Property | Plastic FRC | Steel FRC |
|--------------|-------------|-----------|
| Compression | 1.05 | 1.15 |
| Flexure | 1.10 | 1.35 |
| Impact | >1.00 | 100.00 |
| Toughness | 5.00 | 20.00 |
| Fatigue | >1.00 | 1.90 |
| Permeability | <1.00 | <1.00 |
| Durability | >1.00 | >1.00 |

^aNon-FRC concrete has an assumed index of 1.00.

DESIGN

Structural design using FRC was based on well-defined purposes for the application. Several related project objectives always influenced the material and property selection best suited for the particular application. Summaries of design features using FRC compared to non-FRC for these three project issues, cost, schedule, and performance, are given in the following sections. The information has been obtained by reasoning and from experience with more than \$2 million in work on various projects within chemical plants in the United States. The applications were for slabs, grade beams, and equipment and tower foundations.

Cost

- Steel fibers added \$50 per cubic yard (\$65 per cubic meter) of concrete material.
- Plastic fibers added \$10 per cubic yard (\$13 per cubic meter) of concrete material.
- Superplasticizer for workability added \$5 per cubic yard (\$6.50 per cubic meter) of concrete material.
- Concrete volume was reduced because of reduced sections from improved strength properties.
- Temperature and shrinkage reinforcement was eliminated.
- Some load carrying or strength reinforcement was spaced wider or eliminated by using steel fibers.
- Thinner slab thicknesses because of improved strength properties allowed a reduced amount or less expensive fill material.

Schedule

- Smaller volume amounts of concrete material were used as a result of improved strength properties and therefore allowed: (a) greater surface area for unit volume and therefore faster placement, (b) smaller forms and easier removal or repositioning for faster setup, (c) less excavation time for faster job starts, and (d) reduced access time for trucks, eliminating placement crew waits.
- Superplasticizer speeded up placement and eased workability.
- Superplasticizer reduced or eliminated time spent positioning reinforcement before and after FRC placement.

Performance

- Greater reliability and assurance about reinforcing placement especially with slabs on grade when compared with welded wire fabric.
- Dependence on many individual fibers instead of a few bars.
- More homogeneous behavior and action due to dispersion of reinforcement throughout section.
- Increased joint spacing and less sawing for slabs.
- Higher ultimate strength.
- Better textured surface from fibers at surface for adhesion of coatings, patches, or repair.
- Less piece fracturing or fragmentation resulting in easier removal or modifications to slabs for inserts.
- More ductility to resist unspecified or unanticipated loads.

- More skid or slip resistance due to the texture of the concrete from the fibers at the surface controlled more or less by finishing.
- Extended performance life rather than replacement due to load carrying after initial cracking.
- Less displacement, chipping, and spalling due to more homogeneous reinforcing.
- Availability of a more homogeneous corrosion-resistant material and less micro cracking with reduced permeability. A corrosive exposure to fibers in concrete results in the loss of fibers at that specific location. This is due to their discrete size, orientation, and non-connection to the rest of the concrete beyond the immediate location of corrosive exposure.

The analysis for design using FRC required in many cases the artistic engineering balance between project objectives and the material properties. This may appear intuitively obvious for all structural materials following form and function. However, many of the problems were with finding the material properties of FRC. Not enough empirical or analytical data were available (7).

As an example, consider the design requirement for ACI 318-77 for temperature and shrinkage steel reinforcement. The concepts of reinforcing and bonding are from a surface area, mass, and cross-sectional area relationship. From this, a conventional slab design might allow an 8-in. (20.3-cm) thickness, two layers of wire fabric, and a 20-ft x 20-ft (6.1-m x 6.1-m) size for joint spacing. Steel fiber-reinforced concrete has performed as well as this conventional design with a 3.5-in. (8.9-cm) thickness and a 40-ft x 60-ft (12.2-m x 18.3-m) size for joint spacing. However, there are no formulas available to guide the engineer in comparing conventional concepts of reinforcing and bonding with the fiber design. Consequently, an empirical artistic approach was taken in most cases.

Because an increased joint spacing was possible with the steel FRC, special attention was paid to the joint design and materials used. The materials used to seal the joints needed in most cases to have good weatherability, be easy to install, and cure quickly. Field observation of the 3.5-in. (8.9-cm) thick slab showed excessive joint movement. Fortunately, the joint material chosen could withstand this extension and compression movement (8).

Fiber manufacturers have been extremely helpful for most common design properties. They also usually have some technical pioneers to consult with about what could be expected in various applications. However, because of the variability of concrete in general, FRC property tests are strongly recommended in the locale of the application because the expectations and test results were not always in agreement.

SPECIFICATIONS

Some specification information was available from the fiber manufacturer and other sources concerned about writing specifications (9). However, guide-, edit-, and delete-type specifications have not yet been generally available. Additional information for

design, specification, and construction was obtained from national professional organization publications.

A "first" project seriously considering the use of FRC always appeared to cause uncertainty with everyone involved. Confidence was obtained by placing FRC in the project locale in a small noncritical performance application. This first-hand experience was usually after, or even rather than, a controlled laboratory example. The field experience was recorded with slides or video tape. These visual records were then used with samples and brochures from the fiber manufacturers. This experience, the recording of it, and other information was used in several ways for the benefit of the present and future project applications of FRC by the engineer, owner, concrete producer, and contractor. A simple example of an advantage to this approach was reduction of the uncertainty factor added on to a bid price by a contractor unfamiliar with FRC.

ACKNOWLEDGMENT

Dow Corning has supported this author's interest in fiber-reinforced concrete beyond what would normally be expected of an employer. Several people at Dow Corning and in the community have cooperated with a patient wait-and-see attitude concerning the many aspects of applying fiber reinforced concrete. The fiber manufacturers have contributed much with their field assistance and the resources of their technical pioneers.

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