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Report on Spray-Up and Continuous Strand Glass Fiber-Reinforced Concrete (GFRC)

Reported by ACI Committee 549

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Report on Spray-up and Continuous Strand Glass Fiber-Reinforced Concrete (GFRC)

Reported by ACI Committee 549

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Glass fiber-reinforced concrete (GFRC) is a popular construction material used to manufacture precast concrete products in architectural and civil engineering applications. GFRC products have desirable aesthetics and physical properties, including durability, strength, toughness, moisture resistance, dimensional stability, and fire resistance. This report summarizes the processes, properties, and applications of GFRC made by the spray-up process, and processes that use continuous strands and woven, knitted, or bonded textiles.

Keywords: alkali-resistant glass fiber; architectural panels; cement boards; composites; concrete panels; ductility; durability; fiber-reinforced concrete; filament winding; formwork; glass fiber-reinforced concrete; glass-reinforced concrete; mesh reinforcement; permanent formwork; premix; precast concrete; spray-up process; textile-reinforced concrete; toughness.

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CHAPTER 1—INTRODUCTION AND SCOPE

1.1—Introduction

Glass fiber-reinforced concrete (GFRC) is a composite of alkali-resistant (AR) glass fibers embedded in a cementitious mixture, which could be a paste, mortar, or concrete, possibly with additives and admixtures added for improved processability, properties, or both. The fibers could be short individual fibers or monofilaments; bundles of fibers, which are often referred to as chopped strands; continuous strands or roving, or textiles (Fig. 1.1). Textiles are also synonymously called scrims, fabrics, or meshes.

Only AR glass fibers should be used in GFRC composites, to which this report is confined. There are four processes used to manufacture GFRC:

1) Premix

2) Spray-up, which usually contains a minimum of 4 percent chopped AR glass fiber roving strands by mass of the composite traditionally referred to as GFRC

3) Textile-reinforced concrete (TRC), which uses continuous structured AR glass fibers in woven (typically leno weave), knitted, and bonded constructions such as fabrics, scrims, or meshes

4) Continuous strands in oriented patterns such as filament winding

This report covers Items 2 through 4 and is a companion to ACI 549.3R, which covers Item 1.

GFRC is not just a single material, but rather a variety of materials with different properties and performance characteristics. Because GFRC in any of its forms does not contain steel reinforcing bars, there is no need of extra concrete cover to protect steel against corrosion. This allows it to be produced in thin sections, typically 0.5 to 1.0 in. (13 to 25 mm), which makes GFRC products much lighter in weight compared to conventional concrete products, which are usually 2 in. (50 mm) or thicker, although both are similar in density.

GFRC products have several significant advantages over conventional precast concrete products. They are lightweight, easy to handle and install, and have high toughness. Being lightweight offers cost-effective concrete-based alternatives in applications where the heavy weight of conventional precast concrete would make it unsuitable.

Research on GFRC composites began in the 1960s and has been in successful commercial use for over 40 years. This is proof that, if designed and manufactured to accepted, recommended practices, GFRC has a durability and longevity to be an acceptable building material. Its properties have been thoroughly researched, probably as much as, if not more than, any other material. Further research and development of new applications and mass production processes will move GFRC into the next phase of large-scale use.

Fig. 1.1—Alkali-resistant glass fiber roving, chopped strands, and textile (bonded scrim).

Table 1.2a—Chemical composition of selected glasses, percent of total by mass

Component	A-glass	E-glass	AR glass #1	AR glass #2
SiO_2	73.0	54.0	62.0	61.0
Na_2O	13.0	—	14.8	15.0
CaO	8.0	22.0	—	—
MgO	4.0	0.5	—	—
K_2O	0.5	0.8	—	2.0
Al_2O_3	1.0	15.0	0.8	—
Fe_2O_3	7.0	0.3	—	—
B_2O_3	—	7.0	—	—
ZrO_2	—	—	16.7	17.5
TiO_2	—	—	1.0	—
Li_2O	—	—	—	1.0

1.2—History

Much of the original research performed on glass fiber-reinforced cement paste took place in the early 1960s. This work used conventional borosilicate glass fibers (E-glass) and soda-lime-silica glass fibers (A-glass). The chemical compositions, densities, and mechanical properties of E- and A-glass are listed in Tables 1.2a and 1.2b. Glass compositions of E- and A-glass were found to lose strength quickly because of the high alkalinity (pH ≥ 12.5) of portland cement-based materials. Consequently, early A- and E-glass cementitious composites were unsuitable for long-term use (Larner et al. 1976). Some E-glass products have been developed with alkali-resistant (AR) coatings, but

Table 1.2b—Properties of selected glasses

Property	A-glass	E-glass	AR glass No. 1	AR glass No. 2
Specific gravity	2.46	2.54	2.70	2.74
Tensile strength, ksi (GPa)	450 (3.1)	500 (3.45)	360 (2.48)	355 (2.45)
Modulus of elasticity, ksi (GPa)	9400 (64.8)	10,400 (71.7)	11,600 (80.0)	11,400 (78.6)
Strain at break, %	4.7	4.8	3.6	2.5

these should be viewed with caution because glass filaments are very fine, with typical diameters of approximately 56 × 10^{-5} in. (13 microns). If the coating is degraded physically or chemically, the exposed reinforcing filaments will be quickly degraded away. Also, the ends of the fibers in chopped strands are exposed, and alkalis can wick along the fibers and attack them.

Continued research resulted in the development of AR glass fiber, which improved the long-term durability of glass fiber-reinforced concrete (GFRC). The alkali resistance of AR glass fiber derives solely from its glass composition and is not dependent on surface coatings.

The specifications for AR glass fiber are given in ASTM C1666/C1666M. Alkali resistance significantly increases with increasing zirconia contents up to 16 percent, but only increases slightly with a further increase in zirconia content (Majumdar and Laws 1991; Bentur et al. 1985).

Chemical compositions and properties of commercially available AR glass fiber are provided in Tables 1.2a and 1.2b, respectively. Since the introduction of GFRC in 1970, a wide range of applications in the construction industry have been established. Although much of the research and development was completed in the 1970s and 1980s, more recent work on technology, materials, and application developments was presented at the biennial congresses organized by the Glassfibre Reinforced Concrete Association (1998, 2001, 2003, 2005, 2008, 2011, 2015).

1.3—Scope

This report provides practical information about alkali-resistant (AR) glass fiber-reinforced concrete (GFRC), including a comprehensive compilation of international data and references oriented toward increasing the awareness of producers, engineers, architects, and end users about GFRC technology and its use in a variety of applications. The fundamental principles of materials, mixture proportions, properties, manufacturing processes, and applications of GFRC are reviewed in this report. This report offers an overview of current design practices with references to design guides. The various industrial applications of GFRC include architectural panels, permanent formwork, utility poles, textile-reinforced concrete, and standard panel products.

CHAPTER 2—NOTATION AND DEFINITIONS

2.1—Notation

F_d = ultimate design load, or factored load
F_k = service load
f_u' = assumed (aged) modulus of rupture or ultimate flexural strength, psi (MPa)
f_{ur} = average 28-day modulus of rupture strength of 20 consecutive tests (each test being the average of six individual test coupons), psi (MPa)
f_{yr} = average 28-day proportional elastic limit strength of 20 consecutive tests (each test being the average of six individual test coupons), psi (MPa)
k_1, k_2 = reduction factors
t = student's t—a statistical constant to allow for the proportion of tests that may fall below f_u; the value is 2.539 for the recommended 20 tests
R = resistance
S = actions
s = shape factor
V_f = volume fraction of fibers
V_u = coefficient of variation of the modulus of rupture test strength
V_y = coefficient of variation of the proportional elastic limit test strengths
ϕ = strength reduction factor
γ = ratio of compressive and tensile modulus
γ_f = load factor
γ_{tv} = factor to account for variations in thickness of glass fiber-reinforced concrete
γ_b = factor to allow for difference in bending behavior between test coupon and full-size section
γ_c = factor to account for mode of collapse and consequence of failure
γ_m = partial safety factor

2.2—Definitions

acrylic copolymer—acrylic thermoplastic copolymer is a resinous substance made by reacting acrylic monomers together; the type of copolymer used in concrete and glass fiber-reinforced concrete is an emulsion of submicron-size polymer particles dispersed in water.

alkali-resistant glass fiber—glass fiber using at least 16 percent zirconia by mass.

characteristic strength—value of a strength; for example, flexural, above which 95 percent of the population of all possible measurements of that strength are expected to lie.

creel—framework designed to support roving or bobbins of yarn while being fed into a weaving loom or filament winding machine.

externally bonded fabric-reinforced cementitious matrix—composite material consisting of a sequence of one or more layers of cement-based matrix reinforced with dry fibers in the form of open single or multiple meshes that, when adhered to concrete or masonry structural members, forms a fabric-reinforced cementitious matrix system.

filament—single glass fiber, sometimes called a monofilament.