STONEWEAR®
INFORMATION

PHYSICAL PROPERTIES OF GFRC

The physical properties of glass fiber reinforced composites depend heavily on the fiber content and quality of the mix. They are also influenced by the manufacturing process.
The following discussion refers to a composite made with high zirconia alkali resistant glass fiber.

4.1 – Factors Affecting Properties

The principal factors affecting properties of GFRC are fiber content, water-cement ratio, porosity, composite density, inert filler content (e.g., sand), fiber orientation, fiber length, and type of cure. Density and porosity are also functions of the degree of compaction.

Fiber content, length, and orientation primarily affect early tensile ultimate strength (ETU), early flexural ultimate strength (EFU), and impact strength. The relation of fiber content to these properties is shown in Fig. 12. Higher fiber contents than shown in Fig. 12 tend to entrap air into the composite and reduce density. A minimum fiber content of 4 percent by weight is recommended to ensure adequate ultimate strengths, unless test data shows that reduced fiber contents are adequate for the application.

Fiber length also plays a role in composite ultimate strengths. For GFRC spray-up, the optimum fiber length is 1 1/2 to 2 in.). Shorter lengths, although easier to spray, will not give maximum reinforcement efficiency, and longer lengths may interfere with fiber/slurry laydown and lead to problems similar to those encountered with high fiber contents.

The orientation of reinforcing fibers affects performance. Most GFRC spray-up composites have a two-dimensional random fiber orientation, but if care is not taken during production, fibers can be parallel oriented and the composite material will exhibit different properties when tested along different axes.

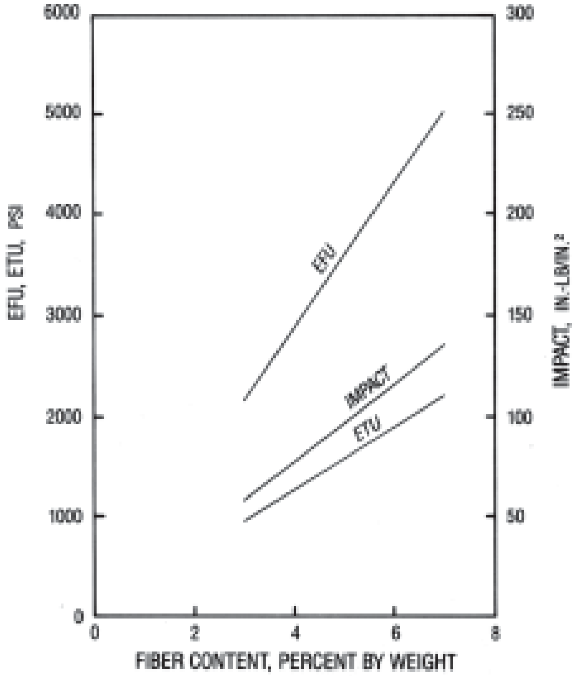


Fig. 12. *Effect of fiber content on early tensile ultimate strength (ETU), early flexural ultimate strength (EFU), and impact strength.*

Composite density affects matrix dependent properties; flexural and tensile strength and modulus of elasticity vary directly with density. Low density reduces ultimate strengths because at lower densities entrapped air reduces the bond between the fibers and concrete. Therefore, proper compaction of the composite is very important. Fiber content has little effect on the modulus of elasticity.

Reprinted from:
Recommended Practice for Glass Fiber Reinforced Concrete Panels
prepared by
PCI Committee on Glass Fiber Reinforced Concrete Panels
Edward S. Knowles, Chairman

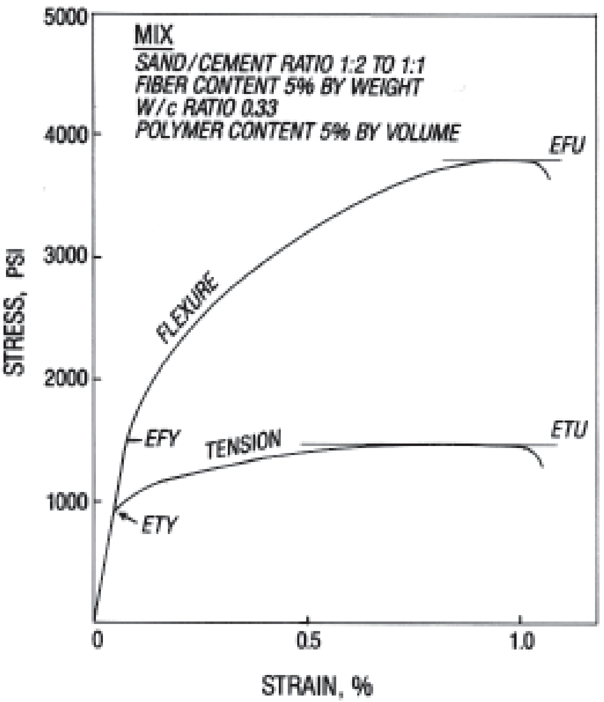


Fig. 13a. *Representative stress-strain behavior of GFRC subjected to flexure and tension tests at 28 days.*

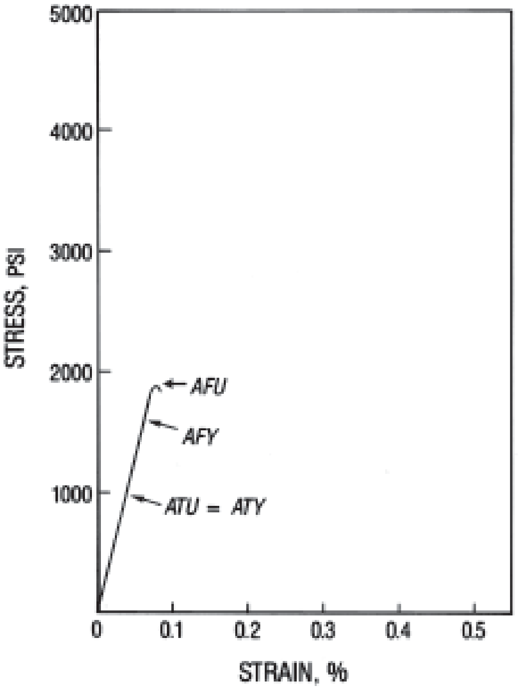


Fig. 13b. *Representive stress-strain behavior of GFRC subjected to flexure and tension tests after aging (equivalent to 50 years).*

Adequate curing results in substantial hydration of the cement. This leads to good bond between fibers and the matrix which improves both fiber- and matrix-dependent properties.

When a GFRC composite is subjected to direct tensile or flexural testing, a stress-strain (load-deflection) curve similar to the idealized curve shown in Fig. 13a is generated.

The initial portion of the flexural curve appears straight, indicating that the GFRC behaves elastically in this region. In reality, microcracking takes place within the matrix and the curve is not linear. The presence of the fibers restricts the growth of microcracks, inhibiting matrix failure and increasing average matrix strength. The point at which the stress-strain curve appears to deviate from linearity is called the yield point. This is the point at which the first major crack has formed.

A substantial amount of energy is required to propagate the crack through the interfaces and the bundles of fibers which lie at the tip of the crack. The energy required is greater than that required to initiate a new crack in the matrix. As a result, instead of cracking all the way through and breaking, a new crack is formed some distance from the first one. As more cracks develop in the surface, the stress-strain curve gradually flattens, indicating a decrease in stiffness.

Further bending or extension of the specimen now brings on a “ductile-appearing” region in the curve due to the multiple cracking. At the end of this region, the development of the crack system is complete and the entire length of the specimen is covered with fine transverse cracks. The load is finally transferred to the fiber reinforcement system, and the specimen cracks open as fibers fracture or pull out. The specimen fails when the reinforcement system can no longer accept an increase in load.

4.2 – Tensile and Flexural Strengths

Loads associated with handling, shipping, and installation. This factor diminishes over the life of the product as the ultimate strength decreases.

4.3 – Modulus of Elasticity

Flexural stress-strain curves are used to determine values of modulus of elasticity for design purposes. Values of flexural modulus of elasticity are normally in the 1.5 to 2.9 X 10^6 psi range, and will vary in accordance with water-cement ratio, sand content, cure, density, and degree of microcracking. There is a lack of a continuous network of microcracks at low stress levels versus a well-developed network of micro-cracks at or near flexural yield strength, thus giving lower E-values than normally associated with precast concrete panels.

4.4 – Compressive Strength

Compressive strength is essentially matrix depen-dent.In-plane (“edgewise”) compressive strength will be somewhat lower than cross-plane strength due to the layers of glass fibers affecting the continuity of the matrix (Fig. 14). Cross-plane compressive strength (“flatwise”) is not influenced by the presence of glass fibers and will be about the same as the compressive strength measured on bulk matrix materials in cube or cylinder tests.

4.5 – Impact Resistance

The impact resistance of GFRC is influenced strongly by the reinforcing fibers. Increasing fiber length from, for example, 1 to 2 in. or using alkali resistant glass fibers with improved sizing, increases impact strength. Cured GFRC at 28 days has higher impact strengths than either unreinforced cement paste or asbestos cement. Impact properties relate to the area under the tensile or flexural stress-strain curve as these curves alter with time, the impact properties are reduced. Normally, impact strength is not a design parameter.

In addition to its higher impact resistance, GFRC’s failure characteristics are different from those of asbestos cement or plain concrete. GFRC exhibits pseudo-duc-tile behavior for several years and damage due to impact is usually confined to the area of impact without evidence of cracks propagating beyond this area. Upon prolonged aging GFRC can be expected to become less ductile, consequently diminishing impact resistance.

4.6 – Shear Strength

Panels made by the spray-up method have fibers randomly distributed in the plane of the section. Therefore, shear values (Fig. 14) vary with the type of load application as follows:

(a) Interlaminar shear. The value of shear strength is that of the matrix. This type of shear stress is encountered in the bending of single skins and vertical load-carrying bonding pads.

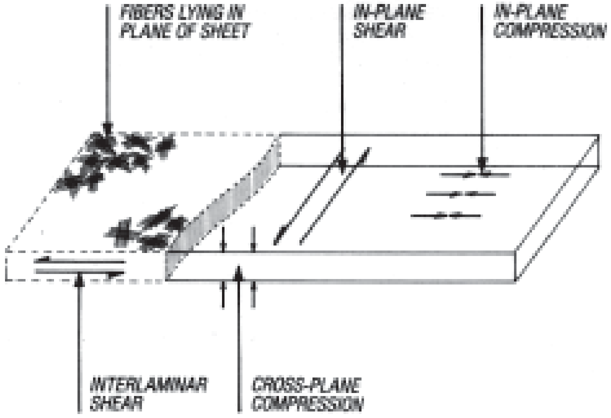


Fig. 14. *Compressive and shear strengths.*

(b) In-plane shear. In-plane shear strength and ulti mate tensile strength for a range of formulations of hand-sprayed GFRC after a variety of aging treatments are identical. Therefore, in the absence of direct inplane shear measurements, tensile strength values may be used with confidence. In-plane shear stress can be generated by bolted connections near the edge of a sheet.

4.7 – Shrinkage and Moisture Movement

As with all concrete, GFRC is subject to shrinkage on drying and partial recovery on wetting. Moisture movement is dependent upon several factors including the water-cement ratio, the sand-cement ratio, curing, and the age of the composite.

The effects of moisture on GFRC are shown in Fig. 15. Irreversible drying shrinkage occurs during the curing stage, and is largely dependent on the sand-cement ratio and the water-cement ratio. Moisture movement causes a reversible dimensional (or volume) change during subsequent wetting and drying. Moisture movement is largely governed by the sand-cement ratio and decreases somewhat with age.

The incorporation of sand, a standard practice, reduces the amount of shrinkage; but shrinkage is still greater than that exhibited by precast concrete because of the higher cement content. Fig. 16 shows the relation between sand content and shrinkage.

Shrinkage induces internal stresses which can lead to cracking, particularly in components constrained by shape, variable section thickness, embedded materials, or external restraint.

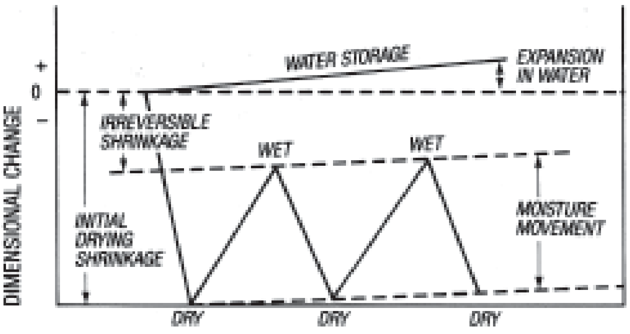


Fig. 15. *Dimensional stability: Moisture movement of GFRC panels.*

Shrinkage cracking can be controlled with adequate fiber content and random fiber orientation. Cracks can run in the direction of the predominant fiber orientation since there are not enough fibers in the direction perpendicular to the direction of cracking to resist crack propagation. Although the addition of glass fiber to the cementitious matrix does not materially reduce its drying shrinkage, it does increase strength and reduce the risk of propagating shrinkage cracking.

Experience has shown that sand-cement ratios of up to 1 can be accommodated without appreciable deterioration of the mechanical strength of the composite. Larger proportions of sand in the GFRC matrix may lead to a reduction in strength and other mechanical properties.

The extent of any dimensional change depends upon the particular GFRC formulation and conditions of exposure. Typically, in laboratory specimens the linear movement from saturated to oven dry is 0.15 percent. Under most climatic conditions, with large shaped building panels the observed movement is about 0.10 percent with a 1:1 sand-cement ratio and 0.35 water-cement ratio.

Small samples show greater moisture movement than do full-sized components. One way of developing shrinkage data is to monitor movements of panels in buildings beginning with measurements of the panel immediately after curing. Periodic measurements of several such panels should provide useful information on the approximate movements which occur in similar panels.

4.8 – Thermal Expansion

Thermal expansion and contraction is governed by matrix properties, primarily the density and amount of sand addition or sand-cement ratio. For typical GFRC mixes the range of the coefficient of thermal expansion is 6 to 9 x 10^{-6} in./in./deg F.

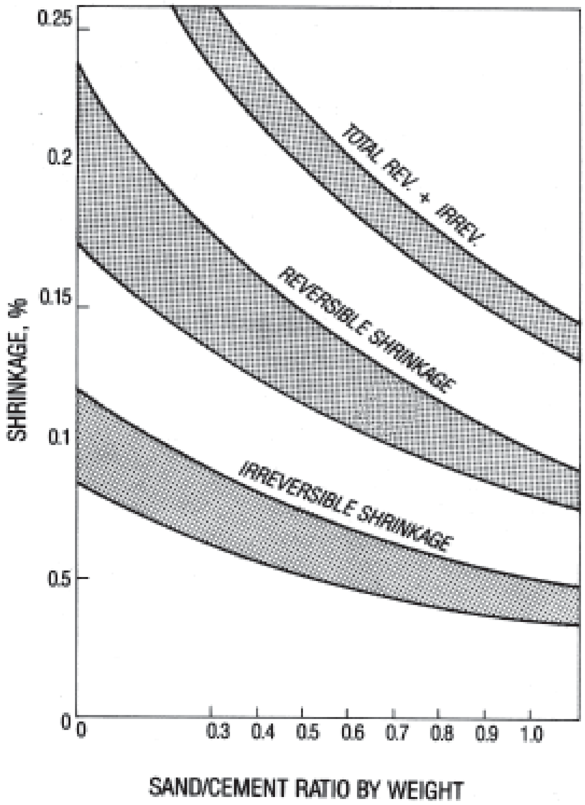


Fig. 16. *Effect of sand addition on shrinkage behavior.*

As with most materials, GFRC expands with increasing temperature; this normal thermal expansion may be counteracted by shrinkage due to moisture loss during the heating of the GFRC panel. Response to thermal and moisture gradients is time-dependent and complex, and depends on initial conditions such as moisture content.

4.9 – Creep

GFRC is capable of sustaining load over prolonged periods. Creep behavior is similar to that of other cement-based materials. Initial elastic deformation is followed by a slow creep deformation under sustained load. The creep rate decreases with time on a logarithmic basis, i.e., the creep deformation occurring from 100 to 1000 hrs. is usually about equal to that occurring from 10 to 100 hrs. An exception to this general rule is found when load is applied to a saturated GFRC specimen. Higher creep deformation is observed in the first hour of loading of saturated specimens than in subsequent logarithmic increments. After

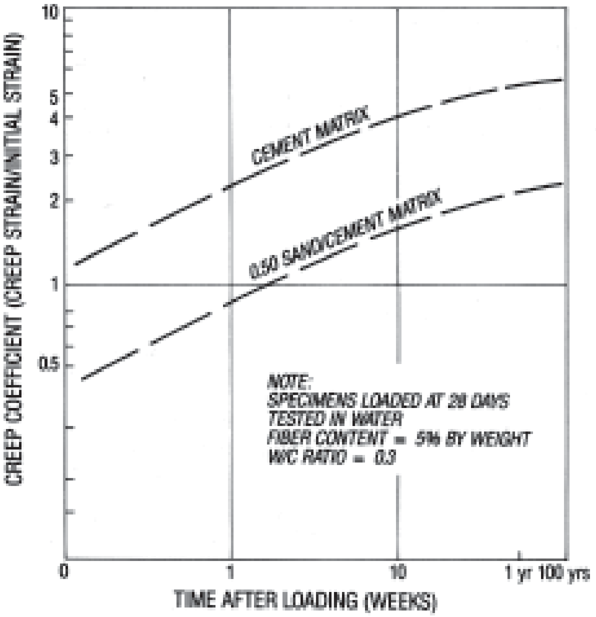


Fig. 17. *Flexural creep of GFRC.*

this time the creep rate parallels that of materials loaded in other environments. Typical creep curves are shown in Fig. 17 for bending stresses below flexural yield (the normal range of working stress). Creep strain is proportional to the initial strain, and creep data may be expressed as the ratio of creep strain to initial strain. In general, creep strains are smaller than expansion/contraction strains due to moisture changes. (Creep under pure tension is not documented; no data are currently available.)

Creep studies with composites indicate that these properties are controlled largely by the matrix. This is expected because of the small proportions (typically 5 percent by weight) of the fiber in the composite. There has been no indication of any adverse creep effects in the composite resulting from the interaction between the matrix and the fiber.

4.10 – Freeze-Thaw Resistance

Experience with GFRC in natural freeze-thaw environments has been good. In order to study the mechanism of behavior a series of laboratory studies have been performed.

ASTM C666, "Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing," Procedure A, gives the most severe exposure of standard unrestrained freeze-thaw tests. In this test, specimens were subjected to alternating cycles of freezing in water at 0 F for approximately 2 hours and thawing in water at 40 F for approximately 1 1/2 hours. GFRC specimens were subjected to freeze-thaw cycles after 0, 8, and 26 weeks of accelerated aging. Unreinforced mortar specimens were subjected to freeze-thaw cycles after 0 and 26 weeks of accelerated aging. For each of these accelerated aging periods, six specimens were tested in flexure after 0, 100, 200, and 300 cycles of freezing and thawing. [Note: accelerated aging was achieved by immersing specimens in lime-saturated water at 122 F to accelerate composite aging.]

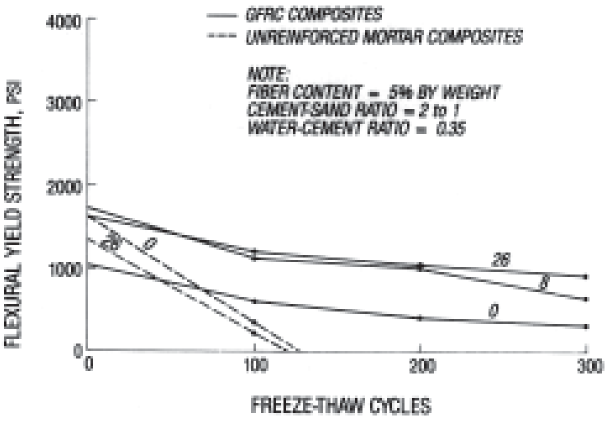


Fig. 18. *Flexural yield strength versus freeze-thaw cycles.*

Flexural yield strength versus freeze-thaw cycles are plotted with solid lines in Fig. 18 for the GFRC specimens and by dashed lines for the companion unreinforced mortar specimens. All curves in Fig. 18 represent matrix cracking strength. Numbers next to each curve indicate the number of weeks in accelerated aging conditions prior to exposure to freezing and thawing.

As shown in the figure, presence of the glass fibers effectively preserved the cement matrix against significant freeze-thaw deterioration. Without fibers, mortar specimens were observed to completely deteriorate before reaching 200 freeze-thaw cycles. In addition, the effect of accelerated aging prior to freeze-thaw exposure had very little effect on the resulting freeze-thaw resistance of the GFRC specimens as indicated by the relatively flat slope of the line for each accelerated aging period.

Flexural ultimate strength versus freeze-thaw cycles are plotted in Fig. 19 for the GFRC specimens. Numbers next to each curve indicate the number of weeks in accelerated aging

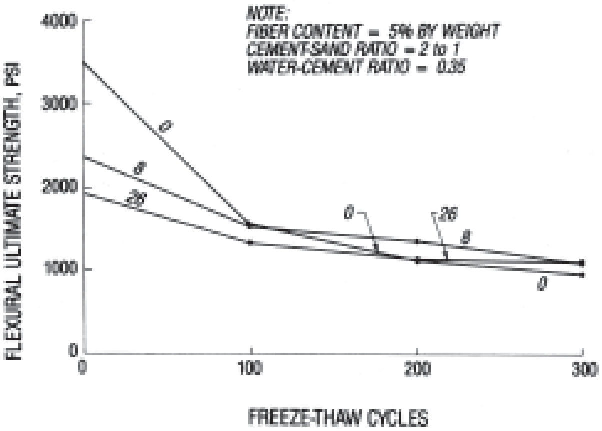


Fig. 19. *Flexural ultimate strength versus freeze-thaw cycles.*

conditions prior to freeze-thaw exposure. As shown in the figure, regardless of the number of weeks in accelerated aging prior to freeze-thaw exposure, the flexural ultimate strength decreases to approximately 1500 psi after 100 cycles and approximately 1000 psi after 300 cycles.

After 300 cycles the GFRC showed slight flaking and fiber prominence on the form side. There was severe flaking of the 'trowel' face and delamination cracks along the edges. The flakes, about 5/32 to 13/64 in. across and 3/64 in. thick, generally remained attached to the main body of the specimen by the glass fibers.

Freeze-thaw tests have been made on test samples cut from sprayed boards containing 5 percent AR glass fiber by weight and 20 percent sand by total weight. The tests were based on the British Standard Test for Asbestos and Asbestos Cement Building Products, BS 4624; 1970 (50 freeze-thaw cycles). These involved samples that were artificially aged by soaking in 122 F water for 90 days then subjected to 50 cycles of 16 hrs at – 4 F in air and 8 hours at 68 F in air, followed by soaking in water for 48 hours.

There was no visible change in the appearance of the samples after the tests, and the mechanical properties of flexural ultimate and yield strengths, modulus of elasticity, and impact strength were not affected.

In practice, the form side of GFRC would usually be the exterior of a component with the more vulnerable trowel face protected from the weather. GFRC is of low permeability and the trowel face would be unlikely to become saturated with water and susceptible to the action of freeze-thaw. Where an integral composite concrete face mix is used, the aggregates in the finish must be compatible with the anticipated weathering exposure as determined by tests or proven performance.

ASTM C666, Procedure A (freezing and thawing immersed in water), provides a very severe freeze-thaw condition and most materials show some degradation. GFRC is no exception but it still compares favorably with older established construction materials and the conclusion is that freeze-thaw conditions do not pose a significant problem in the use of GFRC.

4.11 – Service Performance

Major commercial installations of GFRC panels began in North America in late 1974. Visual examinations to assess the performance in service of these panels have been periodically conducted.

Panels properly designed, produced and installed have shown no visual evidence of structural deterioration or unsoundness of panels in service. In general, connections and joint sealants are performing satisfactorily. Smooth GFRC surfaces have been prone to display surface crazing. This is of no structural significance, but it does not enhance appearance, particularly where atmospheric pollution has resulted in surface staining. Exposed aggregate and textured surfaces have weathered well and withstood atmospheric pollution.

Care in detailing can minimize the incidence of surface staining, particularly by controlling the flow of rainwater run-off, as is the case with precast concrete detailing.

4.12 – Fire Endurance

GFRC made of cement, glass fibers, sand, and water is non-combustible and meets the requirements of ASTM E136, "Test Method for Behavior of Materials in a Vertical Tube Furnace at 750 deg C." When used as a surface material, its flame spread index is zero. In addition, tests for non-combustibility, ignitability, and fire propagation have been conducted in England in accordance with the appropriate British Standard on "Fire Tests on Building Materials and Structures," BS 476, Parts 4, 5, and 6. GFRC made with an acrylic thermoplastic copolymer dispersion

Table 1. Descriptions of wall panel assemblies fire tested in the U.S.A.

Fire Endurance	Outside Wythe	Steel Studs or GFRC Ribs		Insulation	Inside Wythe	Overall Thickness	Test Ref.
		Type	Maximum Spacing				
2 hr*	3/8 in. GFRC; 6 in. Returns	5 in. Ribs	24 in. (nominal)	5 in. TFB	5/8 in. GWB-C	7-3/8 in.	21
2 hr	1/2 in. GFRC; 5 in. Returns	4 in. Studs	16 in. (nominal)	5 in. TFB	1/2 in. + 1/2 in. GWB-C	6-1/2 in.	23
2 hr	1/2 in. GFRC**; 1-1/2 in. Returns	6 in. Studs	24 in. (nominal)	5 in. TFB	1/2 in. + 1/2 in. GWB-X	9 in.	24
1-1/2 hr	1/2 in. GFRC; 5 in. Returns	4 in. Studs	16 in. (nominal)	5 in. TFB	5/8 in. GWB-C	6-1/8 in.	22

** Surface of inside wythe exposed to fire.* *** Contained 5% acrylic thermoplastic copolymer by volume of GFRC*

GFRC *= glass fiber reinforced concrete*
GWB-X *= Type X gypsum wallboard*
GWB-C *= Sheetrock brand Firecode C gypsum wall panels produced by United States Gypsum Co.*
LW *= lightweight concrete, a structural grade concrete made with lightweight aggregates, such as expanded clay, shale, slag, slate or fly ash, portland cement, water, and with normal weight or lightweight sand, and having a unit weight between 90 and 120 pcf.*
NW *= normal weight concrete, a structural grade concrete made with natural aggregates and having a unit weight of 135 to 155 pcf.*
SMF *= sprayed mineral fiber as manufactured by U.S. Mineral Products Co., consisting of refined mineral fibers and inorganic binders; water is added during the spraying operation.*
TFB *= Thermafiber CW 40 batts produced by United States Gypsum Co.*
VCM *= vermiculite cementitious mixture as manufactured by the Zonolite Division of W.R. Grace & Co., consisting of vermiculite aggregate and inorganic binders; water added prior to spraying.*

for curing purposes may or may not pass the ASTM E136 test, but will have a flame spread index of less than 25.

Single skin GFRC panels can be designed to provide resistance to the passage of flame but fire endurances as defined in ASTM E119, “Methods of Fire Tests of Building Construction and Materials,” of greater than 15 minutes are primarily dependent upon the insulation and fire endurance characteristics of the materials in the back-up or core.

Fire tests conducted in the U.S.A. of GFRC wall panels have concentrated on assemblies made with steel studs of GFRC ribs and insulated with fire resistant mineral fiber insulation. Results of these tests are summarized in Table 1. It should be noted that the tests were conducted in accordance with ASTM E119 which requires hose stream tests in addition to fire resistance tests.

Based on results of fire tests conducted in England and engineering studies, the following panel configurations and joint treatments should qualify for the fire endurances indicated in Tables 2 and 3.

Joint Treatments One-Stage Butt Joints. One of the assemblies listed in Table 1 consisted of GFRC panels with 1 1/2 in. returns. In that assembly the joints were 3/4 in. wide, but instead of using ceramic fiber felt to firestop the joints (Table 3), a 5-in. thickness of TFB insulation (Fig. 20) was placed between the steel studs across the backs of the returns. The same insulation was used between the other studs in the assembly.

The joints in the assemblies with 5- and 6-in. returns listed in Table 1 were 1/2 in. wide and were protected with a 5-in. initial depth of the same TFB insulation as that used in the assemblies.

4.13 – Acoustical Properties

GFRC follows the mass law for sound reduction. For skins of similar design, but different weights, the STC increases approximately 6 units for each doubling of weight. GFRC’s relatively high density offers good attenuation characteristics. A 3/8 in. sheet of GFRC at 4 psf provides a sound transmission class (STC) of 34 (see Fig. 21). However, a complete panel assembly will provide greater sound reduction conforming to most code requirements.

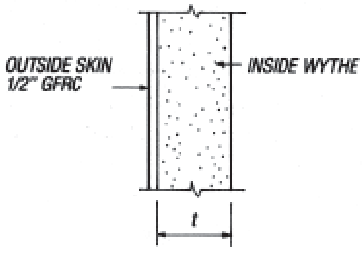
4.14 – Density

The dry density of spray-up GFRC depends primarily on fiber content, water-cement ratio, polymer content, sand addition, compaction, and spray techniques. These factors also influence

Table 2. Thicknes *(t)* of inside wythe of various materials for panels with outside wythe of 1/2 in. GFRC.* Surface of inside wythe exposed to fire.

Fire Endurance	*t*, Inside Wythe			
	NW	LW	SMF	VCM
1 hr	3 in.	2 3/8 in.	7/8 in.	7/8 in.
2 hr	4 1/2 in.	3 3/8 in.	1 5/8 in.	1 5/8 in.
3 hr	5 1/2 in.	4 1/4 in.	—	—
4 hr	6 1/2 in.	4 7/8 in.	—	—

** Subtract 1/4 in. from tabulated values of t for panels in which 1/2 in. exposed aggregate finish is applied to GFRC.*



porosity. The typical range of density is 120 to 140 pcf. A knowledge of the density gives information on the general quality of manufacture and is used as a measure of plant quality control procedures.

4.15 – Thermal Conductivity

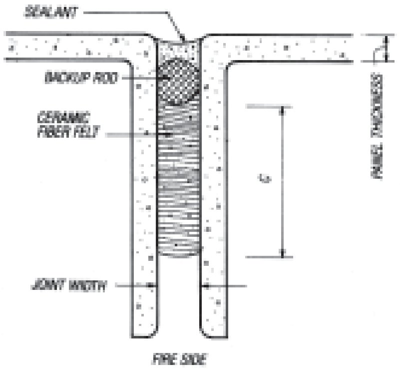
Thermal conductivity of GFRC is dependent upon composite density and moisture content. The typical range of thermal conductivity is 3.5 to 7.0 BTU/in./hr./ft.^{2}/ deg F.

4.16 – Permeability

The porosity of the GFRC matrix tends to distribute water throughout the system uniformly and rapidly but does not seem to increase the transport of the water from one side of the sheet to the other. Laboratory tests have shown that no signs of moisture would appear on the inside of a 3/8 in. sheet of GFRC with rain blown onto it by a 73 mph wind. Water vapor permeability of GFRC will range from 5 to 11 perm-in. for GFRC materials made at 0.25 and 0.35 water-cement ratios, respectively. Highly compacted GFRC tends to have a lower water vapor permeability than less well compacted GFRC.

Table 3. Depth of ceramic fiber felt and joint width for various endurances.

Fire Endurance	Joint Width	Depth (c) of Ceramic Fiber Felt
1 hr.	3/8 in.	1/2 in.
2 hr.	3/8 in.	3/4 in.
1 hr.	1 in.	1 in.
2 hr.	1 in.	2 1/4 in.



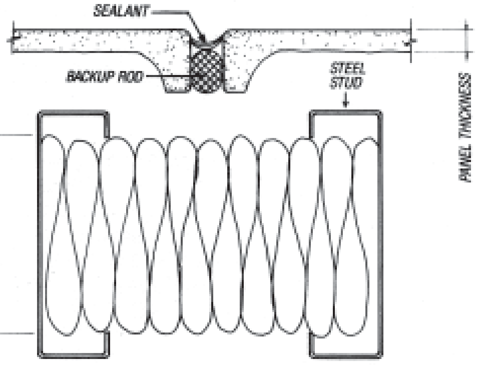


Fig. 20. *Use of TFB insulation behind one-stage butt joint with 1 1/2 in. return.*

Most formulations of the material have a vapor permeance of less than 3 perms, making the need for an additional vapor barrier subject to vapor flow calculations.

Air permeability of GFRC ranges from 4.6 perm-in. for GFRC exposed to 40 percent relative humidity to 0.2 perm-in. for GFRC exposed to 90 percent relative humidity.

PHYSICAL PROPERTIES
OF
GFRC

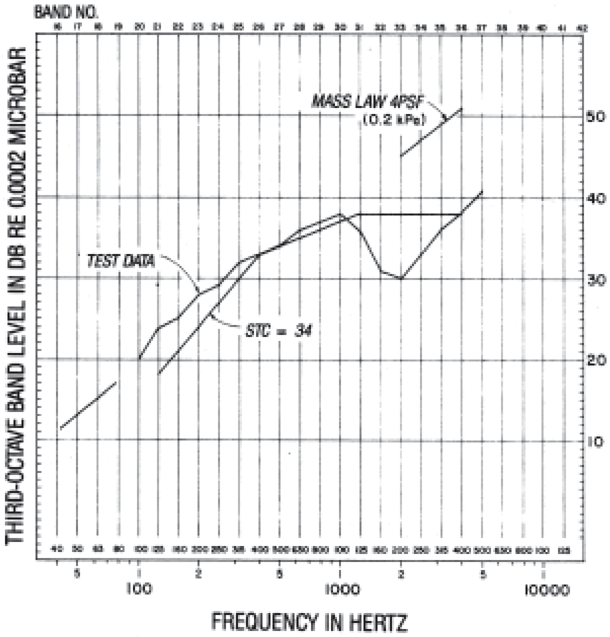


Fig. 21. *Relationship of sound reduction and frequency.*

The air and water vapor permeances of GFRC decrease as a function of time and storage under natural weather conditions. These properties are largely those of the cement matrix and compare favorably with those of other building materials.

4.17 – Moisture Absorption

Moisture absorption varies according to the density of GFRC but will normally be in the range of 11 to 16 percent by weight. Moisture content in an environment of 65 F and 60 percent relative humidity will reach equilibrium in the range of 4 to 8 percent by weight.

4.18 – Property Summary

Different manufacturers may achieve different ranges of values of physical properties of GFRC. Specific values of properties should be supplied by the manufacturer to the designer. For general information, Table 4 gives ranges of 28 day property levels which should be attainable by competent operators using sand-cement ratios of between 1:3 to 1:1, and predicted 50 year aged properties.

Table 4. Typical Range of GFRC Properties*

Property	28-day, (E)	Aged**, (A)
Density (dry)	120 to 140 (pcf)	120 to 140 (pcf)
Impact strength (Charpy)	55 to 140 (in. lb/in.^{2})	20 to 28 (in. lb/in.^{2})
Compressive strength (edgewise)	7,000 to 12,000 (psi)	10,000 to 12,000 (psi)
Flexural: Yield (FY)	900 to 1,500 (psi)	1,000 to 1,600 (psi)
Ultimate strength (FU)	2,500 to 4,000 (psi)	1,300 to 2,000 (psi)
Modulus of elasticity	1.5 x 10^6 to 2.9 x 10^6 (psi)	2.5 x 10^6 to 3.5 x 10^6 (psi)
Direct tension: Yield (TY)	700 to 1,000 (psi)	700 to 1,100 (psi)
Ultimate strength (TU)	1,000 to 1,600 (psi)	725 to 1,100 (psi)
Strain to failure	0.6 to 1.2 (percent)	0.03 to 0.06 (percent)
Shear: Interlaminar	400 to 800 (psi)	400 to 800 (psi)
In-plane	1,000 to 1,600 (psi)	725 to 1,100 (psi)
Coefficient of thermal expansion (77 to 115 F)	6 to 9 x 10^{-6} (in./in./deg F)	6 to 9 x 10^{-6} (in./in./deg F)
Thermal conductivity	3.5 TO 7.0 (Btu/in./hr/ft^2/deg F)	3.5 TO 7.0 (Btu/in./hr/ft^2/deg F)

** These are typical values and are not to be used for design or control purposes. Each manufacturer must test production composites to establish physical properties for design. The values achieved in practicewill be dependent on mix design, quality control of materials, fabrication process and curing.*

*** Developed from accelerated testing programs on GFRC specimens immersed in 50 to 80 deg C water. On the basis of comparisons between behavior in real weather and accelerated tests, predictions can be made of properties for 50+ years in different climates.*