An evaluation of the use of finely ground E-glassfiber as a pozzolan in GFRC composites.

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Summary

The paper will give results of accelerated tests on glassfiber-reinforced concrete (GFRC) composites containing a range of contents of VCAS/Micron HS, which is a finely ground E-glassfiber material. The tests were designed to evaluate the pozzolanic effect of VCAS/Micron HS. The paper will also describe practical issues of processing GFRC containing this material, such as mix workability, the effect on finish and colour, and its effect on set time and curing.

Keywords: VCAS™, vitreous calcium aluminosilicate, E-glassfiber, ground glassfiber, pozzolan, GFRC

1. Testing

1.1. Introduction

It has long been known that pozzolans help improve the long-term performance of glassfiber-reinforced concrete (GFRC). Dr Majumdar and the research staff at the Building Research Establishment (BRE) first examined the effect of fly ash [1]. Since then there has been substantial work undertaken with other pozzolans, such as silica fume [2–4] and metakaolin [5].

This paper discusses a new pozzolan that has been introduced that is based on finely ground E-glassfibre. The reason for the development of alkali-resistant (AR) glassfiber was because, although E-glassfibers gave good reinforcing effects in GFRC in the early days, their effect quickly diminished because the E-glass reacted with the alkalis in the Portland cement. VCAS™ (vitreous calcium aluminosilicate) pozzolans utilise this reactivity of E-glass with alkalis.

VCAS pozzolans use scrap E-glassfiber as a primary ingredient. The ground E-glassfibers are blended with lime and alumina compounds and heated to a molten state which is then solidified by quench cooling, processed, and ground to a fine white powder which has highly reactive pozzolanic characteristics. This paper deals with VCAS-micronHS (hereafter referred to as VCASHS) which has a median particle size of 3 µm. The chemical composition of VCASHS is shown in Table 1 and the physical properties are shown in Table 2.

Silica, SiO2	50-55%	Titania, TiO2	<1%
Alumina, Al2O3	15-20%	Phosphorous oxide, P2O5	<0.1%
Iron oxide, Fe2O3	<1%	Manganese oxide, MnO	<0.01%
Calcia, CaO	20-25%	Boron oxide, B2O3	0-6%
Magnesia, MgO	<1%	Sulphur oxide, SO3	<0.1%
Sodium oxide, Na2O	<1%	Chloride, Cl	<0.01%
Potassium oxide, K2O	<0.2%	Loss on ignition, LOI	<0.5%

Table 1 – Chemical Composition of VCASTM Pozzolans

	VCAS-micronHS
Specific Gravity	2.6
Bulk Density, Loose lb/ft^3	40-44
Medium Particle Size, μm	3
Passing No. 325 Mesh, %	99.9
Specific Surface Area, cm^2/g	8,500
Pozzolanic Strength Index, 28d, % control	127
Brightness, %	92
Melting Point, °C	1200
Hardness, Mohs	5.5

Table 2 – Physical Properties of VCAS-micronHS

VCASHS meets the technical requirements of ASTM C618 [6] for use as a supplementary cementing material and when blended with Portland cement it exceeds the requirements of ASTM C1157: *Standard Performance Specification of Hydraulic Cement* [7]. It also meets the accelerated pozzolanic activity index, ASR control, and sulphate resistance requirements of ASTM C1240 for silica fume [8].

1.2. Materials, mix designs, and test methods

Materials:

Cement:	Grey ordinary Portland cement (OPC)
Sand:	Silica sand (30/40 mesh)
Pozzolan:	VCAS-Micron HS
Polymer:	Polyplex acrylic co-polymer
Superplasticiser:	Masterbuilders Rheo1000
AR-glassfiber:	NEG 2500H103 roving

Basic formulation:

Cementitious material*	47 lb
Sand	47 lb
Water	14 lb
Polyplex	5 lb
RheoBuild 1000	3 oz
Nominal glass content	5%

*Cementitious material refers to the mix of OPC and VCASHS. In this test programme the VCASHS replaced an equal weight of OPC. Therefore the cementitious material to sand and the cementitious material to water ratios were kept constant.

1.3. Test procedures

All testing was done under the supervision of Professor Thomas Harmon, Clifford Murphy Professor of Civil Engineering, Washington University in St Louis, MO.

A control test board without VCASHS was made, which would provide the base comparison for the other test boards. Four test boards were made with VCASHS replacements of 15, 25, 30 and 35% OPC. All test boards were made by the spray-up process using a rotor/stator pump and concentric spray gun. The test boards were made in accordance with ASTM C1228

[9], with the exception that the boards were made larger because more test coupons were required for the accelerated aging test. All test boards were 0.5 inches thick.

Following spraying, the boards were covered with plastic sheet and allowed to cure over night. The following day the plastic sheet was removed and the boards were stripped from the moulds and stored for 28-day air curing. They were cured at ambient temperature and humidity, which varied from a daytime high of 80°F to a night-time low of 60°F. Humidity was not recorded.

Figure 1 – Flexural Strength Test Rig

At 28 days the boards were cut into test coupons measuring 12 × 2 inches. Testing was done with four-point bending on a 10-inch span in accordance with the requirements of ASTM C-947-03 [10] (see Figure 1). The cross-head deflection speed was 0.1 inches per minute.

Figure 2 – Hot Water Tanks with Water Temperature Controls

The daytime zero strength was measured for the control board and one set of coupons of each of the VCASHS test boards. The remaining coupons were placed in hot water tanks (Figure 2) and aged for varying durations according to ASTM C1560-03 [11]. The coupons were placed in the tanks on edge on wood racks approximately 0.5 inches apart (Figure 3). The coupons from each test board were kept in a separate water tank. The water temperature was maintained at 60°C. At specified intervals, the coupons were removed from the tanks and tested in accordance with ASTM C-947-03 [10].

Figure 3 – Test Coupons Placed in racks inside the Hot Water Tank

1.4. Test results

The test results are summarised in Figures 4–10. Figures 4–6 show f_u (modulus of rupture (MOR)), strain to failure, and f_y (limit of proportionality (LOP)) values for all the boards plotted against total time immersed in hot water. Figures 7–10 show the stress–strain curves at day zero compared to day 49.

1.5. Discussion

Strain to failure data in Figure 5 are represented as the ratio of deflection at ultimate strength divided by deflection at yield. Accelerated aging was undertaken for 70 days which is equivalent to 50 years of natural weathering in the UK [1].

Figure 4 shows that all VCASHS percentage replacement levels improved long-term flexural strength compared to the control. There was little difference in strength at 70 days between the different levels.

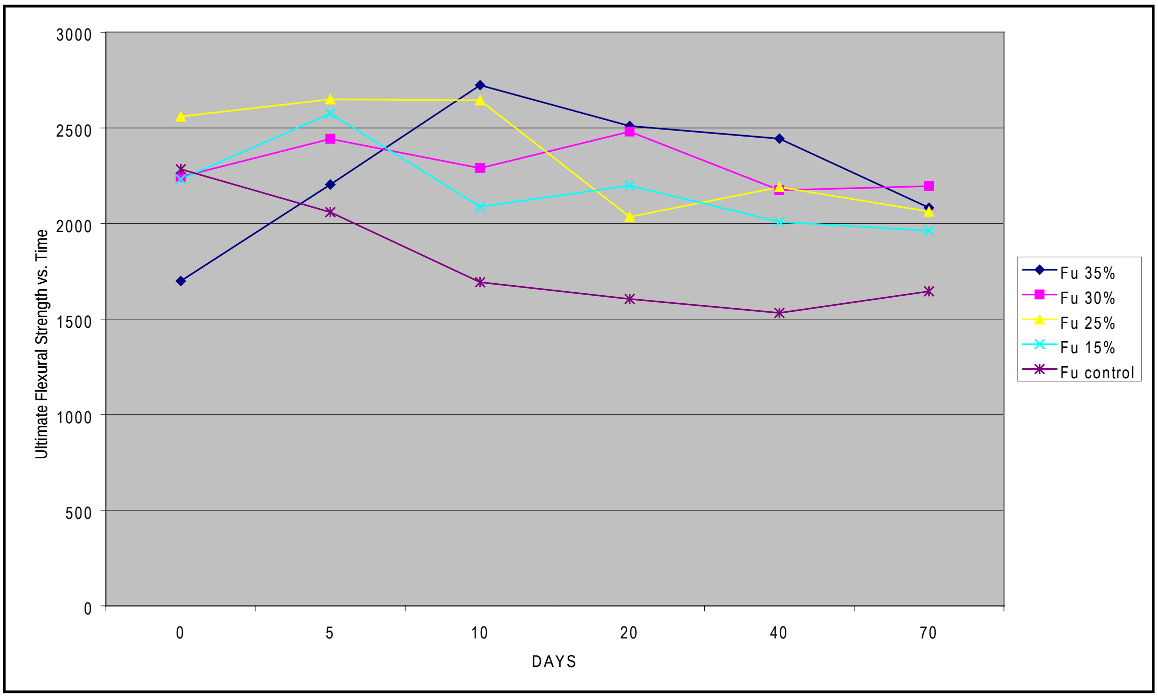

Figure 4 - Ultimate Flexural Strength vs. Time

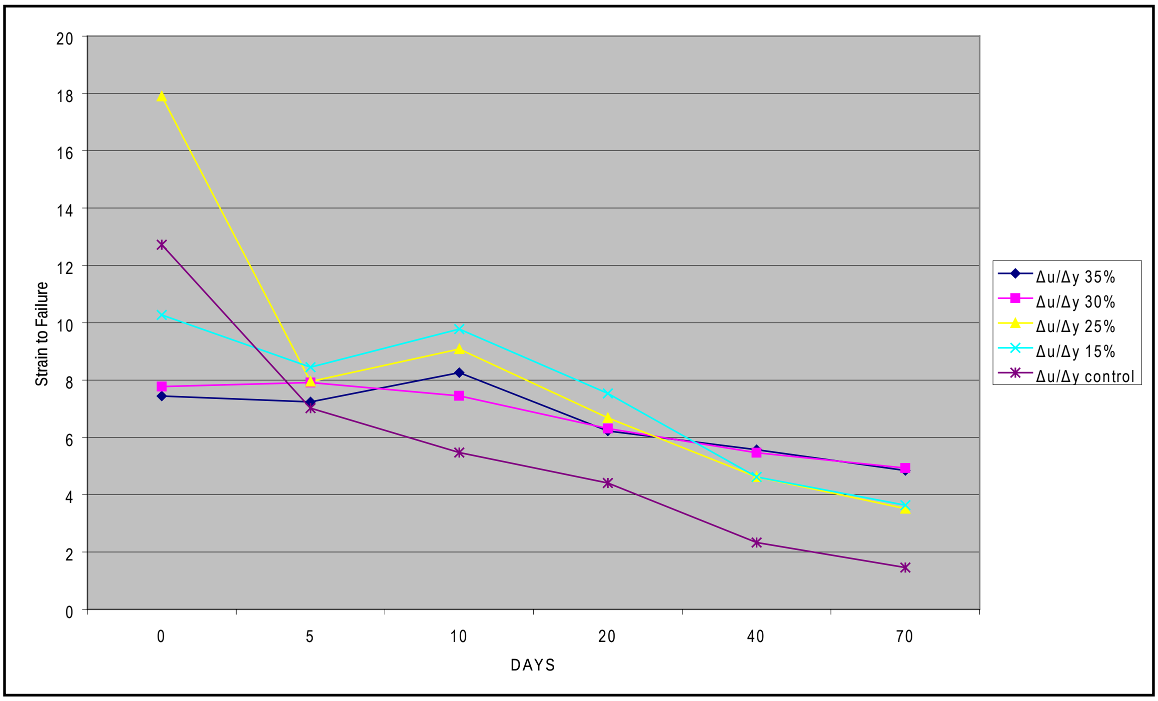

Figure 5 - Strain to Failure

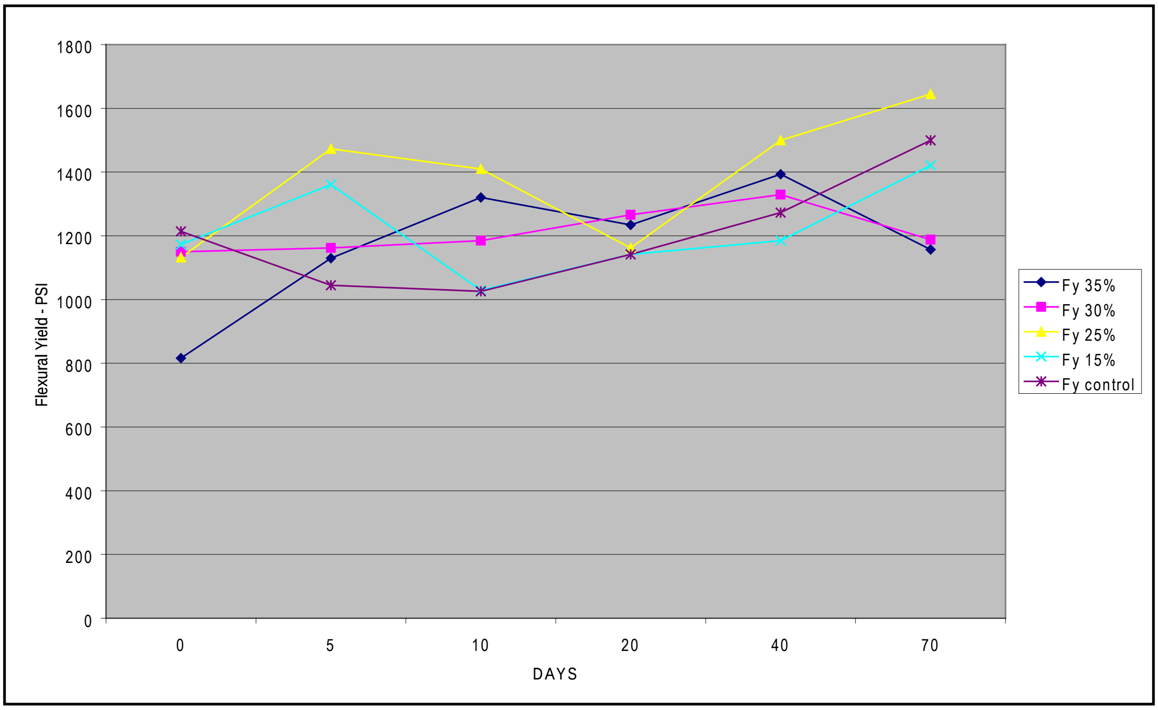

Figure 6 - Flexural Yield vs. Time

Figure 6 shows that the incorporation of VCASHS does not significantly affect yield when compared to the control. The 15 and 25% levels had fairly constant yields, similar to the control although the higher levels, 30 and 35%, did show a fall in yield strengths at 70 days. It is not clear if this is just a test anomaly or an actual long-term effect.

Both Figures 4 and 6 indicate that the 35% level did retard the rate of gain of strength as shown by the low start strengths, both yield and ultimate, but then there was a significant strength gain over the first 10 days.

All replacement levels showed improved retention of strain to failure compared to the control. The 30/35% levels showed slightly better retention than the 15/25% levels. The authors are checking on the day zero value for the 25% level because it appears to be considerably higher than all other values. The retarding effect of the 30/35% levels seems to show in lower start strain to failure values.

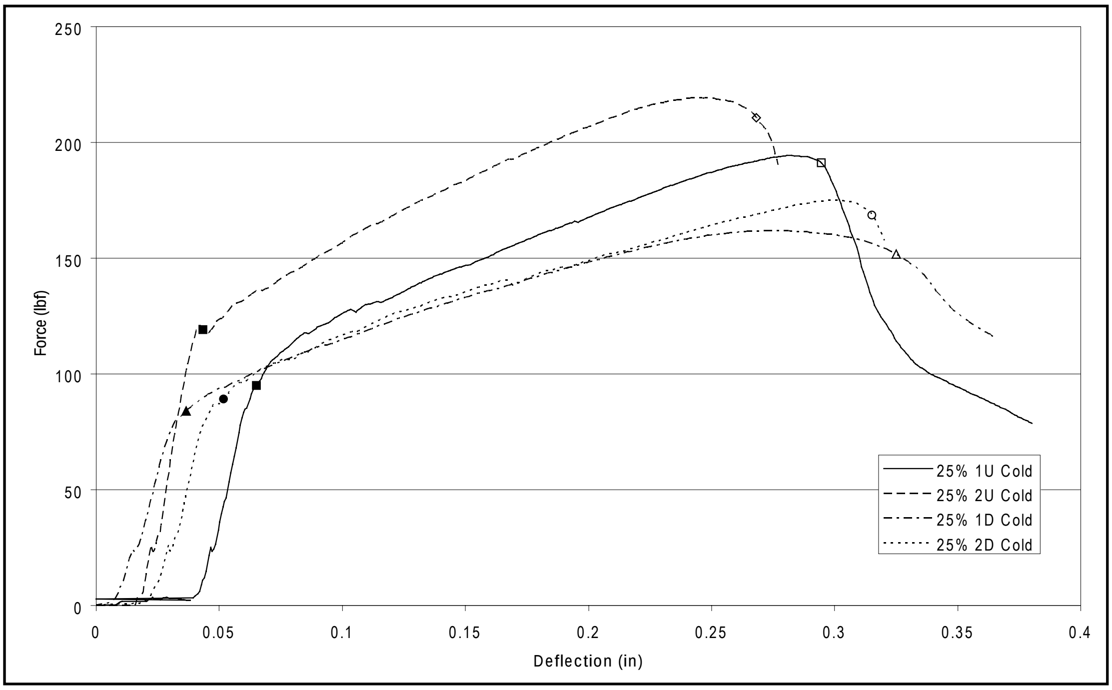

Figure 7 – Stress vs. Strain Chart at Day Zero for 25% VCASHS Composite

Figures 7–10 show the stress–strain curves for the 25% level and the control at start of testing and at 49 days. The charts show that both composites had similar ductility at day zero but the 25% level composite had significantly more than four times the ductility at 49 days.

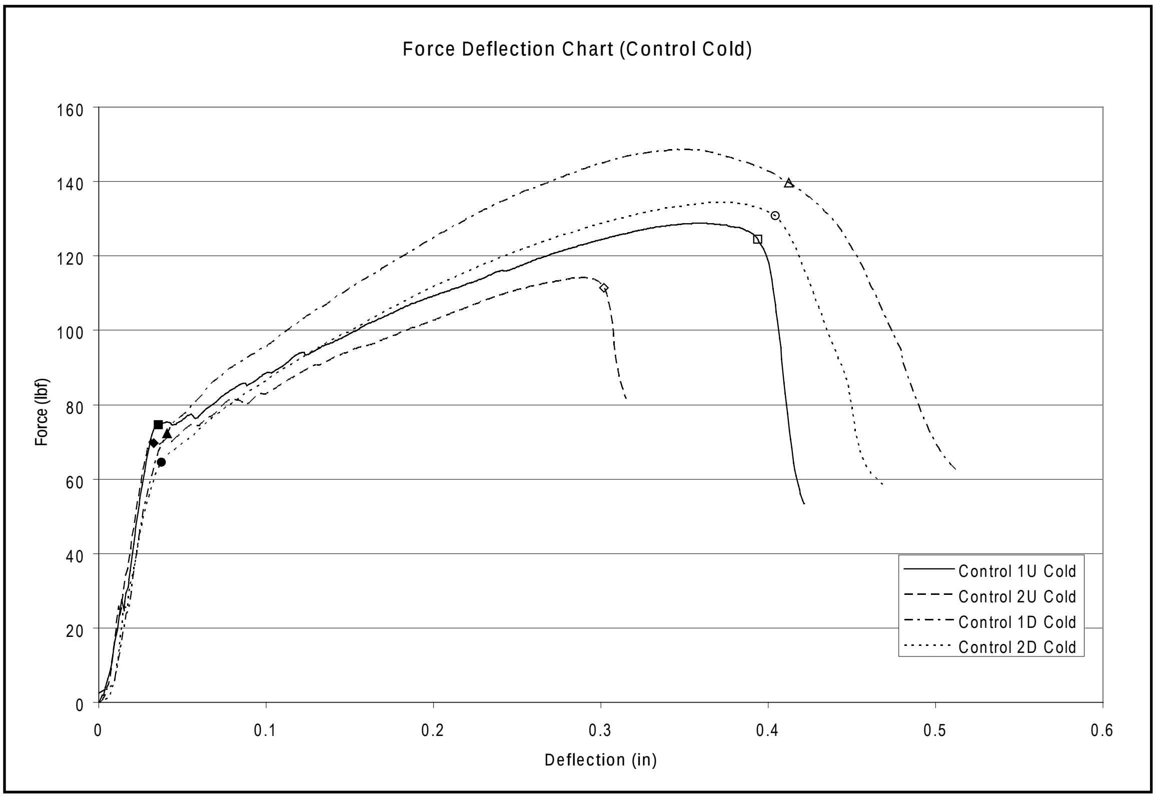

Figure 8 – Stress vs. Strain Chart at Day Zero for Control Composite

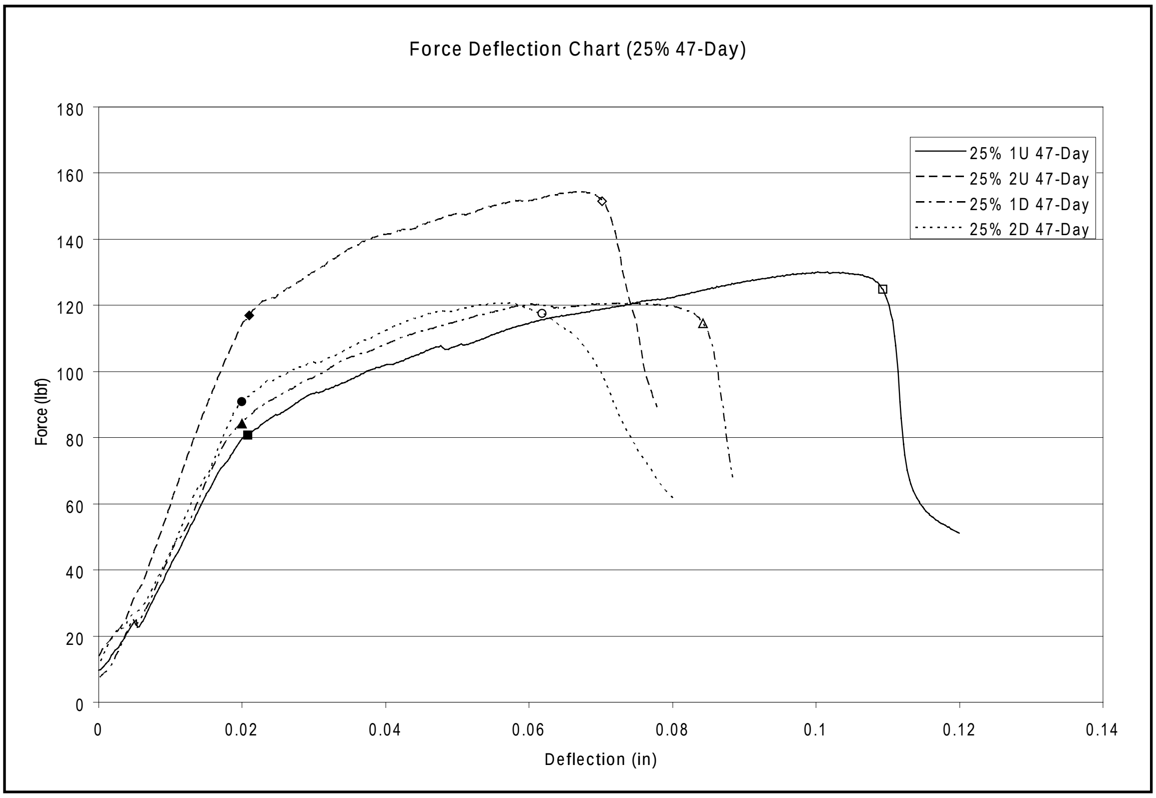

Figure 9 – Stress vs. Strain Chart at 49 Days for 25% VCASHS Composite

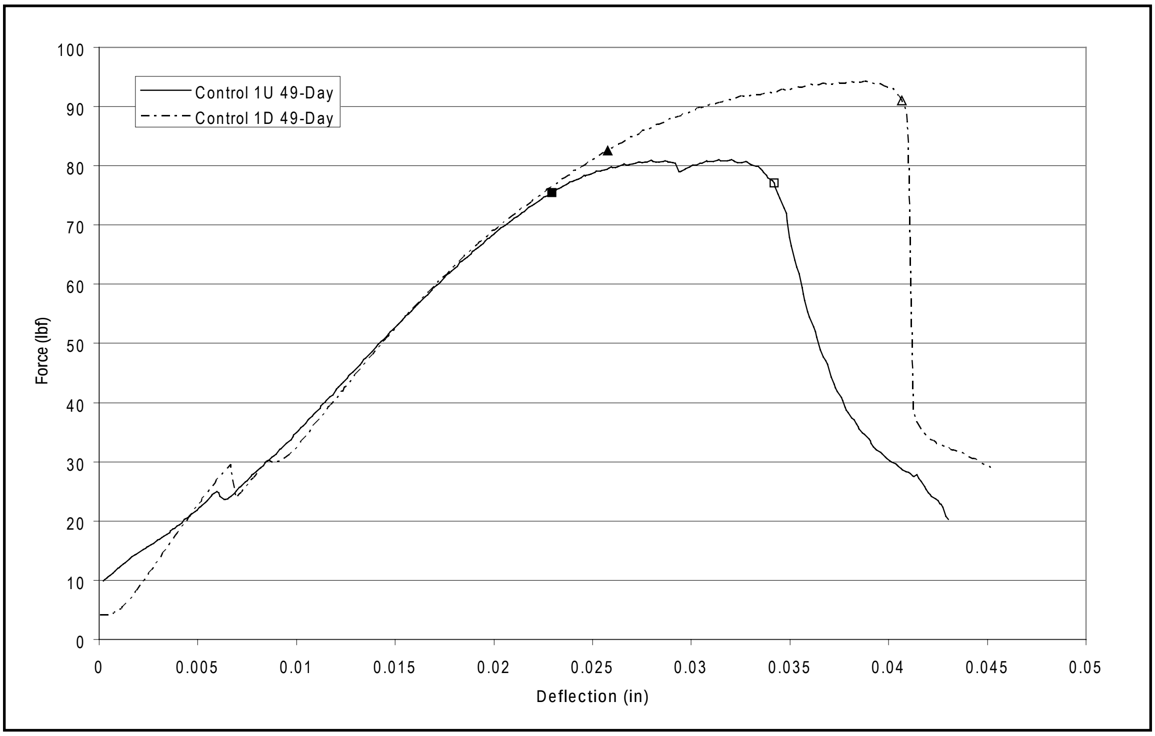

Figure 10 – Stress vs. Strain Chart at 49 Days for Control Composite

1.6. Conclusions

1. All replacement levels of the VCASHS improve the long-term flexural strength and strain to failure of GFRC when compared to the control, which was the GFRC mix formulation that is typically used in the USA.
2. The addition of VCASHS also helped retain long-term ductility.
3. There were no apparent detrimental effects of adding VCASHS, except that the 35% level did appear to retard the rate of gain of strength. However, the strengths were similar to the other levels at 10 days.
4. The 25% replacement level gave the best overall performance without any detrimental effects and it is therefore the authors' recommended addition level.

2. Application

2.1. The pozzolanic reaction

When Portland cement reacts with water the tricalcium silicate and dicalcium silicate react with water to form calcium silicate hydrates (CSH) and approximately 20–25% calcium hydroxide. At the time of these reactions the pore water can reach pH levels of 13 or higher. At this high pH level the silicate structure of the VCASHS pozzolan is broken down and reacts with the calcium hydroxide to form additional calcium silicate hydrates.

An excess of water is required in all concrete mixes to hydrate the cement and to create a workable mix with favourable flow characteristics. Once the excess water evaporates from the matrix it creates void spaces in the concrete that inevitably become a conduit for aggressive ions.

It is dichotomous that water is the creator of the matrix and but is also central to most durability problems in concrete. In porous materials, water is known to be the cause of physical and chemical processes of degradation. The rate of deterioration is dependent on whether the attack is confined to the surface of the concrete, or whether it is taking place inside the material. Water is the most abundant fluid in nature with very small molecules that can penetrate into extremely fine pores or cavities. Water is capable of dissolving more compounds than any other known liquid.

Low permeability should be considered synonymous with durability. Therefore, filling the voids with additional CSH formed from the reaction of VCASHS and calcium hydroxide will create an almost impermeable and durable concrete with a long service life.

Primary and secondary efflorescence is dramatically reduced by limiting the egress and ingress of moisture which in turn reduces the movement of calcium hydroxide and other soluble alkalis to the surface of the concrete.

2.2. Mix design considerations and spray-up

VCASHS has a specific gravity of 2.60 compared to OPC which is approximately 3.15. When VCASHS replaces OPC on an equal weight basis there will be an increase in paste volume. At a fixed w/c ratio, a 20% replacement of cement with VCASHS would create a 4.2% increase in paste volume. The difference in specific gravity translates into an improved yield of cementitious product and a mixture with a creamier and more cohesive consistency.

When spraying GFRC through a concentric gun or premix through a premix spray gun, the slurry containing VCASHS need not exceed a three-ring slump. The mixture will appear somewhat stiffer than one made with OPC. Once the mixture is pumped and sprayed it will fluidise. Therefore the mist, face or backup coat can be applied in the usual way. Having a creamier and more cohesive mix will reduce time and labour typically associated with spraying vertical sections of moulds.

Another consideration when using VCASHS would be to increase the sand fraction in the mix. The amount of additional sand would be dependent on the gradation and shape of the sand being used in the mix. One could easily increase the sand content by 18–20% using a well-graded sand with round particles compared to 10–12% using a manufactured sand with angular shapes.

VCASHS particles have a low surface area with smooth surfaces and will require 10% less mix water compared to metakaolin and silica fume. The mix water requirements for VCASHS replacement levels of 15–35% of the Portland cement remained unchanged. Workability at these replacement levels could not have been achieved using metakaolin or silica fume.

2.3. Curing and strength using VCASHS

Highly reactive pozzolans such as metakaolin and silica fume typically have the least impact on initial strength. VCASHS at 25% replacement of cement falls into this performance category and can reach and surpass the control strength in three days.

Sufficient overnight strength can be achieved by following the steps outlined below.

1. Maintain a minimum curing temperature of 65°F.
2. Cover the product with plastic film to maintain a high humidity.
3. At lower curing temperatures, cover the plastic film with an insulated blanket to retain heat of hydration.

2.4. LEED certification and the US Green Building Council

VCASHS is a post-industrial waste product that is eligible for LEED (Leadership in Energy and Efficient Design) points determined by the US Green Building Council, based on the recycled content in construction products. For every ton of cement replaced by VCASHS, carbon dioxide emissions are reduced by 1 ton, 3.5 million BTUs of energy are saved and 1.5 fewer tons of cement feedstocks are mined.

2.5. Conclusions

1. At the 25% replacement level VCASHS will significantly reduce secondary efflorescence in GFRC composites.
2. The cost of adding VCASHS to a GFRC mixture is mitigated by the increase in paste volume and sand content.
3. Products that have been manufactured using VCASHS are shown in Figures 11–12.

Figure 11 – Large Planters

Figure 12 – Large Flower Pots

References

1. Majumdar, A.J. & Laws, V. *Glass Fiber Reinforced Cement*. Published on behalf of the Building Research Establishment by BSP Professional Books, 1991, Ch. 5, section 5.2.2, pp. 94–101.

2. Hayashi, M., Sato, S. & Fuji, H. Some ways to improve durability of GFRC. *Proceedings of a Symposium on Durability of Glass Fiber Reinforced Concrete*, Chicago, November 1985, Precast Concrete Institute, Chicago, 1986, p. 270.

3. Bentur, A. & Diamon, S. Effects of direct incorporation of microsilica into GFRC composites on retention of mechanical properties after aging. *Procceedings of a Symposium on Durability of Glass Fiber Reinforced Concrete*, Chicago, November 1985. Precast Concrete Institute, Chicago, 1986, p. 337.

4. Soukatchoff, P. & Ridd, P.J. High durability glass-fiber reinforced cement using a modified cementitious matrix. *Proceedings of the Glass Reinforced Cement Association (GRCA) 8th Biennial Congress*, Maastricht, the Netherlands, 21–24 October 1991, p. 45.

6. American Society for Testing and Materials. *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete*. ASTM, West Conshohocken, PA, 2005, ASTM C618-05.

7. American Society for Testing and Materials. *Standard Performance Specification for Hydraulic Cement*. ASTM, West Conshohocken, PA, 2003, ASTM C1157-03.

8. American Society for Testing and Materials. *Standard Specification for Silica Fume Used in Cementitious Materials*. ASTM, West Conshohocken, PA, 2005, ASTM C1240-05.

9. American Society for Testing and Materials. *Standard Practice for Preparing Coupons for Flexural and Washout Tests on Glass Fiber Reinforced Concrete*. ASTM, West Conshohocken, PA, 2004, ASTM C1228-96.

10. American Society for Testing and Materials. *Standard Test Method for Flexural Properties of Thin-Section Glass-Fiber-Reinforced Concrete (Using Simple Beam With Third-Point Loading)*. ASTM, West Conshohocken, PA, 2003, ASTM C-947-03.

11. American Society for Testing and Materials. *Standard Test Method for Hot Water Accelerated Aging of Glass-Fiber Reinforced Cement-Based Composites*. ASTM, West Conshohocken, PA, 2003, ASTM C1560-03.