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# The Mechanical Properties of Alkali Resistance Glass Fiber Reinforced Cement under Different Curing Conditions

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The mechanical properties of alkali resistance (AR) glass fiber reinforced cement (GFRC) under different curing conditions were investigated in this study. The specimens were formed by extrusion process, and then steam cured and autoclaved. An autoclaved specimen showed the elastic-brittle behavior up to 4% of fiber volume fraction. However, it was found that the fracture behavior for steam cured specimen was changed to the elastic-plastic with crack branches fracture at greater than 3 vol.% of fiber.

***Key words :*** GFRC, Steam curing, Autoclave, Mechanical properties, Microstructures

## I. Introduction

Cement is an useful material for construction field because it has good compressive strength, durability and economical competition. However, cement matrix is brittle, so cement products have weaknesses for tensile strength and ductility. To improve that defects, concrete which is reinforced by steel bar is of wide application that is reinforced concrete structure (RC structure).

For small size production (e.g., board & panel) the reinforcing system with fibers can be applied. Especially thin products, flexural property is more important than other mechanical ones. In order to improve flexural performance, fiber reinforcement is employed in various concrete structure.1) Reinforcement effects depend on the individual materials constituent (fiber, matrix and interface), fiber geometry (aspect ratio) and fiber orientation.2)

The one of the most popular reinforcement fiber for FRC (fiber reinforced cement) is asbestos. Asbestos has a good tensile strength, alkali resistance, durability and low cost. Despite of these excellent properties, asbestos is classified the carcinogenic material because its dust may cause the lung cancer.

There are another reinforcement fibers, such as ARG (alkali resistance glass fiber), carbon fiber, polypropylene fiber, polyethylene fiber, polyvinyl alcohol fiber, etc. These reinforcement fibers have poor reinforcing effects comparing with asbestos, because they are still expensive and low physical properties for cement composites. Among these fibers, ARG is general-used fiber in GRC (glassfiber reinforced cement). Some previous studies, alkali resistance of ARG is no good for cementious matrix. And their conclusions have been not satisfied the ARG's alkali resistance property.

As for GFRC, it has been known that the mechanical property was degraded3,4) after long-term exposure to weathering because glass fibers were damaged by the reaction with the highly alkaline cement matrix.5) While most of previous reports were in the condition of moist curing from 20°C to 65°C, test in the present work was conducted at a relatively high temperature. ARG was compared with E-glass fiber for the property of alkali resistance under autoclaving condition by using SEM analysis.

## II. Experimental Procedure

### *1. Raw materials*

The chemical compositions of cement and silica powder are shown in Table 1.

And hydroxy propyl methyl cellulose was used as a plasticizer for extrusion process. The characteristics are shown in Table 2.

Table 3 showed the physical properties of ARG and E-glass fiber.

**Table 1.** Chemical Compositions of Starting Materials

| | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $R_2O$ | Ig-loss | Blain-value ($cm^2/g$) |
|---|---|---|---|---|---|---|---|---|
| Cement | 21.5 | 5.3 | 3.1 | 64.2 | 3.0 | -- | -- | 3,350 |
| Silica Powder | 93.10 | 2.48 | 2.42 | 1.23 | 0.47 | 0.30 | -- | 2,750 |

**Table 2.** Characteristic of Plasticizer (Hydroxy Propyl Methyl Cellulose)

| Bulk Density | Viscosity | Remarks |
|---|---|---|
| 0.40 | 30,000 cps | aqueous solution 2%, 20°C<br>RV type 20rpm |

**Table 3.** Physical Properties of Fibers

| | ARG | E-glass |
|---|---|---|
| Density (g/cm$^3$) | 2.78 | 2.54 |
| Diameter (μm) | 14-16 | 16 |
| Length (mm) | 6, 12 | 6 |
| Aspect ratio (L/D) | 490, 860 | 460 |
| Tensile strength (kgf/mm$^2$) | 250 | 350 |
| Elastic modulus (kgf/mm$^2$) | 7200 | 7400 |
| Elongation at rupture (%) | 3.6 | 4.8 |
| Incombustibility | melting | melting |

### 2. *Manufacturing the specimen*

The proportion of the matrix and fibers is shown in Table 4. All of mixing is represented by weight. AR-glass fiber was mixed with cement using an Omni mixer, followed by a mixing with other ingredient for 2 minutes. Then dry mixed composite was mixed with water by a kneader for 3~5 minutes. At that time, small amounts of water and kneading time were varied with a fiber content. Fig. 1. illustrates the flow chart for manufacturing of GFRC specimen.

**Table 4.** Batch Proportions of the Specimens Used in the Study (by wt.%)

| Fiber volume fraction (%) | Cement Silica powder | ARG | HPMC | Water* |
|---|---|---|---|---|
| | Controlled CaO/SiO$_2$ mole ratio is 0.86 | | | |
| 0 | 99.35 | 0.00 | 0.65 | 25.8 |
| 1 | 98.12 | 1.20 | 0.68 | 27.2 |
| 2 | 96.89 | 2.39 | 0.72 | 28.6 |
| 3 | 95.62 | 3.62 | 0.76 | 29.8 |
| 4 | 94.36 | 4.83 | 0.81 | 31.3 |

* Proportion of water is based on the total amount of dry law material.

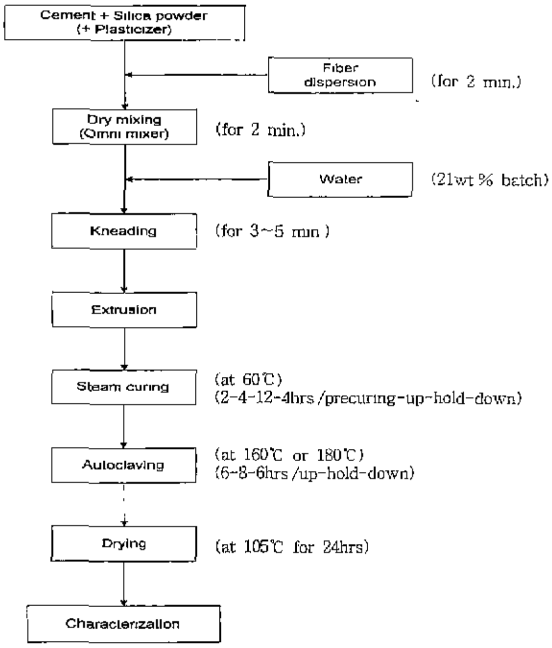


**Fig. 1.** Flow chart of the specimen preparation.

### 3. *Charaterization of specimen*

The board-shape specimens having the size of 450× 80×10 mm were made by a vacuum extruder. All specimens were steam-cured at 60°C for 12 hours and half of them were autoclaved at 180°C for 8 hours. And then all samples were aged for about 1 week and dried 24 hrs. before testing. The mechanical property was tested with a three-point loading employing the computer controlled testing machine (Autograph AG-10TE) with a span of 300 mm and a loading speed of 5 mm/min.

## III. Results and Discussion

### 1. *Flexural Strength*

The plain matrix (i.e, without fiber) cured by steam or autoclave are very brittle but their flexural strength were different.[6] Fig. 2. showed that the flexural strength increased with fiber volume fraction for both an autoclaved specimens (ACS) and steam cured specimens (SCS). *It also showed that the reinforcement effect by fiber length was less than that by fiber volume fraction.*

All ACS were consistent in reinforcement factors by fiber volume fraction and length. However the flexural strength of 3~4% fiber volume fraction of SCS increased just slightly or decreased. It could be found that the some fiber pull-out at the fracture section of these specimen.

Especially at over 3% of fiber volume fraction, increasing ratio of flexural strength was decreased or negative. The main factor was loading effect by fiber volume fraction. High volume fraction caused some bad conditions as follows;

1) reverse effect for extrusion forming
2) bad condition of fiber dispersion
3) difficult for compaction of GFRC composite

As a result, these factors can be described by increasing the fiber bundles in the specimen.

### 2. *Load-deflection curve*

The load-deflection curve as shown in Fig. 3 depicted the sudden loss of strength after formation of crack at

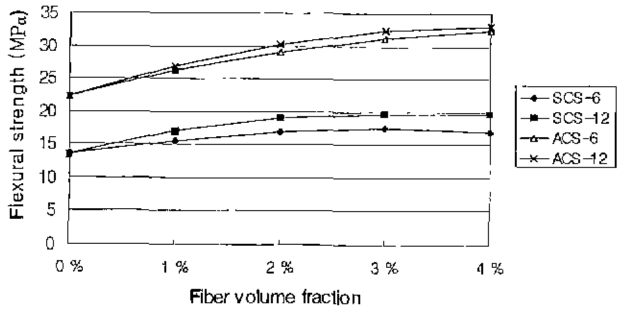
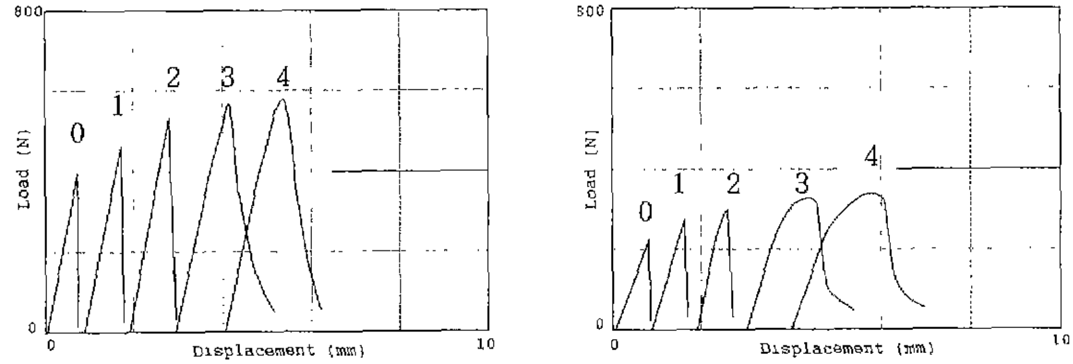


**Fig. 2.** Effect of fiber volume fraction on flexural strength of steam cured and autoclaved GFRC.



(a) ACS (b) SCS

**Fig. 3.** Load-deflection curve of SCS (a) and ACS (b) with varing fiber content.

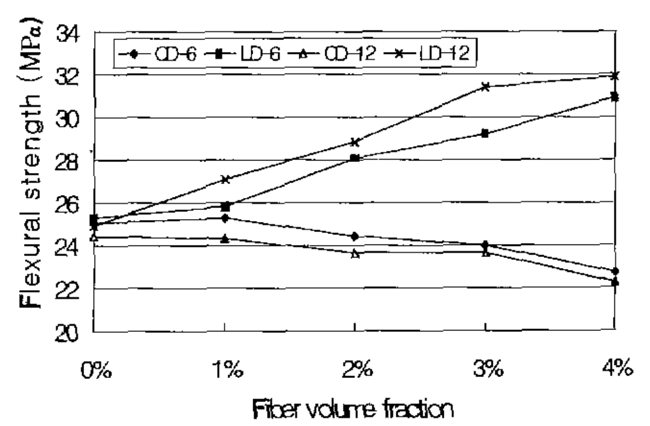


**Fig. 4.** Flexural strength of LD and CD in various fiber content. (LD=Line Direction, CD=Cross Direction, Specimen size=120×40×10 mm, Span=80 mm)

the peak load.[7] ACS showed the elastic-brittle behavior up to 4% of fiber volume fraction. While the fracture behavior of SCS was changed to the elastic-plastic with crack branches from 3 vol.%. It was thought that the adhesion strength between fiber and matrix was not sufficient, so the fracture behavior of SCS was not affected by ultimate strength of fiber.[8] AR-glass fiber had a brittle character because it had a very short elongation at rupture. This implied that the post-cracking zone for SCS was caused by fiber pull-out.

### 3. *Fiber orientation*

Fiber orientation is also one of reinforcement factors. Fiber orientation is dependent on the manufacturing method. Just placing the fiber-cement mixture into formwork has no fiber orientation. In other words, vector

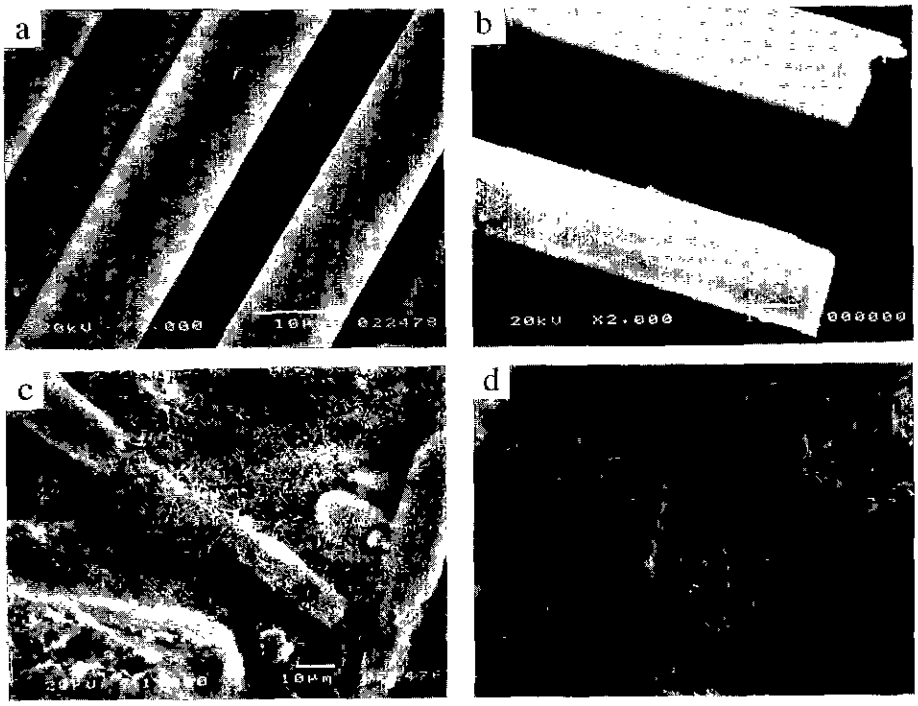


**Fig. 5.** SEM of AR-glass fibers of SCS and ACS. Virgin fiber (a), SCS (b), ACS (c) and E-glass fiber as reference (d).

value of fibers is zero in the 3-dimension.

Forming processes such as fiber spray process, Hatschek process, extrusion process have fiber directions. While two specimens show the same flexural strength of LD (line direction), they do not always show the same value of CD (cross direction). In order to estimate the actual fiber reinforcement effect totally, it must be checked the flexural strength of LD and CD.

The flexural strength of line direction was increased by fiber content. However those of the cross direction was slightly decreased by fiber content (Fig. 4). These showed that the fiber was arranged into extrusion direction because this direction was received relatively small shear stress of fluidity during extrusion.

### *4. Corrosion of fiber*

Fig. 5 is the SEM photographs of glass fibers in the specimens. It showed that no visible corrosion of glass fiber occurred at the interface for SCS. But there were small amount of cement hydrate formed at the interface between fiber and matrix. On the other hand, the fibers in the ACS clearly show the corrosion of the surface. It might be thought that formed cement hydrate was tenaciously bonded to the glass fiber at the interface. As a consequence of surface corrosion, glass fibers became weaker with the curing temperature. The chemical stability of the interfacial zone was important, but the improved properties of ACS are to be retained.

## IV. Conclusions

The mechanical properties of alkali resistance glass fiber reinforced cement under different curing conditions were investigated. The fibers used here were 6 and 12 mm in length, and the volume fractions were varied from 1% to 4%. These mixtures were formed by extrusion process, and then steam cured and autoclaved.

It was found that the flexural strength depended upon not only factors such as fiber volume fraction, fiber aspect ratio and fiber orientation but also curing conditions. The autoclaved specimen showed the elastic-brittle behavior up to 4% of fiber volume fraction. However the fraction behavior for steam cured specimen was changed to the elastic-plastic with crack branches fracture from 3vol.% of fiber.

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