Properties of 3D glass fibre fabric reinforced cement-based composite

Z. LIU, Q. CUI & Q. LI
China Building Materials Academy, China

Abstract

As a new-type of Glass fiber Reinforced Cement (GRC), 3D glass fiber fabric reinforced cement is a composite of 3D glass fiber fabric and high performance cement mortar. So far the most commonly used glass fiber product in GRC is chopped glass fiber, glass fiber mesh or the combination of both, this sometimes leads to inaccurate position of reinforcement material in the matrix. This problem can be effectively solved by using 3D glass fiber fabric, other benefits include high tensile strength, good durability, and hence 3D glass fiber fabric could be a suitable reinforcement material to make thin-wall precast elements. To develop a thin-wall elements used in building cladding panels, study on the properties of GRC made of 3D glass fiber fabric and high performance cement mortar was conducted. Results show that 3D-GRC has good mechanical properties and durability. Being a material with high strength and high ductility, it is anticipated to be successfully used in cladding panels.

Keywords glass fiber reinforced cement (GRC), 3D glass fiber fabric, high performance cement mortar, mechanical property, durability, cladding panel

INTRODUCTION

Glass fiber reinforced cement (GRC) is a kind of high performance cement-based composite, it has many advantages like lightweight, high mechanical properties and good freezing-thaw cycle resistance[1]. The glass fiber in the matrix can effectively improve the brittleness of the cement mortar and enhance its tensile strength [2]. Sometimes there will be some problems when adding the glass fiber into the matrix. When we choose the chopped glass fiber as the reinforcement material, the enhancement effect is not obvious if the reinforcement ratio is too low, on the other hand, the glass fiber will not only affect the mortar's workability but also hard to disperse if the reinforcement ratio is too high. These will also lead to the damage of GRC product when the stress concentrated in some area. When we choose the glass fiber mesh as the reinforcement material, its position in the matrix will change as it is a flexible material. This makes the actual strength of GRC product depart from its design strength which strict its application in engineering.

In order to improve the reinforcement ratio of glass fiber and optimize the position of glass fiber, we use the 3D glass fiber fabric as the reinforcement material. The content in this alkali-resistant glass (AR-glass) fiber is 16.7%, its elastic modulus is 72GPa and the tensile strength is 1700MPa. The upper and bottom surfaces of the fabric are contacted by the continuous stem fiber to form the hollow structure, as shown in Figure 1.

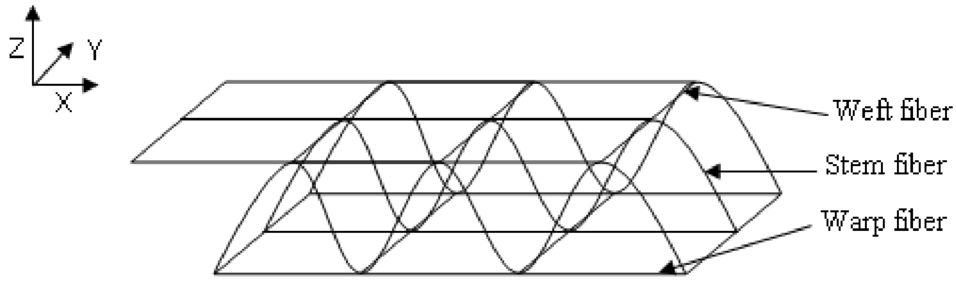

***Figure 1**. The structure of 3D glass fiber fabric*

The 3D glass fiber fabric is made of three kinds of yarns like the warp fiber (X direction), the weft fiber (Y direction) and the stem fiber (Z direction) [3]. The warp fiber is straight and the weft fiber is flexural. Three different spatial distribution of yarns make the 3D glass fiber fabric as a whole exhibit anisotropic characteristics. Both the ends of the stem fiber are in the upper and bottom surfaces, combined with the yarns in the surfaces, to make the upper and bottom surfaces as a whole structure. The density of warp fiber or weft fiber and the height of stem fiber can all be adjusted. The 3D glass fiber fabric can be used to make the composite adapt to a variety of requirements.

The 3D glass fiber fabric can not only make the hollow structure lightweight composite but also make the structure and function sandwich composite by filling some materials into the hollow structure[4,5]. Currently the 3D glass fiber fabric has rapid development in wind power, aerospace, transportation and other fields. Some scholars are trying to combine the 3D glass fiber fabric and phenolic foam or polyurethane foam to make the structure and function insulation composites[6-8]. In this research, we use the 3D glass fiber fabric as the reinforcement material to make the cement-based composite. The mechanical properties, freezing-thaw cycle resistance and ageing properties of 3D-GRC are all tested.

MATERIALS

1) Cement: 42.5 grade early-strength sulphoaluminate cement, its oxide composition and properties are listed in [Table 1] and [Table 2].
2) Glass fiber: 3D glass fiber fabric made of AR-glass fiber with the 16.7% content, its properties are listed in [Table 3].
3) Sand: river sand, fineness modulus is 3.14, maximum grain size is 2mm, fines content is 1.2%.
4) Admixture: superplasticiser made by China Building Materials Academy.
5) Water: Tap water

***Table 1.** Oxide composition of sulphoaluminate cement w/%*

Table 2. *Main properties of sulphoaluminate cement*

Table 3 *Main properties of 3D glass fiber fabric*

METHODS

GRC formulation

We make the GRC samples according to GB/T 15231-2008 *Test methods for the properties of glass fiber reinforced cement*. The fluidity of the mortar mixture drops after the glass fiber added. We adjust the water to keep the similar fluidity about 285±3mm by JC/T 986-2005 *Cementitious grout*. Table 4 lists the GRC formulation studied in this paper.

Table 4. *GRC Formulation k*

S1 is the blank group without any glass fiber; the one layer glass fiber mesh is fixed at the position about 3mm away from the bottom surface; the two layers glass fiber meshes are fixed at the position about 2mm away from the upper and bottom surfaces; the 3D glass fiber fabric is set at the position about 1mm away from the bottom. For each formulation, several GRC sample panels are prepared and cured in a cabinet for 3 days at 95% RH, 20℃. After curing, the panels are cut into test coupons measuring 250mm×50mm×10mm and 120mm×50mm×10mm, as shown in Figures 2 and 3.

Figure 2. Flexural strength test samples

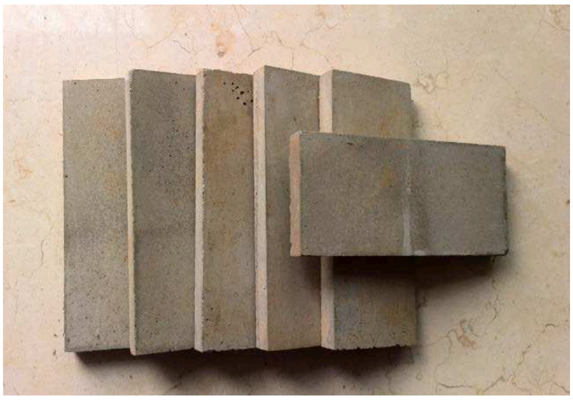

Figure 3. Impact strength test samples

Flexural strength test

Flexural strength tests are carried out by a WD4100 electronic testing machine, in four-point loading, with a span of 210 mm and a loading speed of 5 mm/min. The limit of proportionality (LOP) and modulus of rupture (MOR) are recorded, as shown in Figure 4.

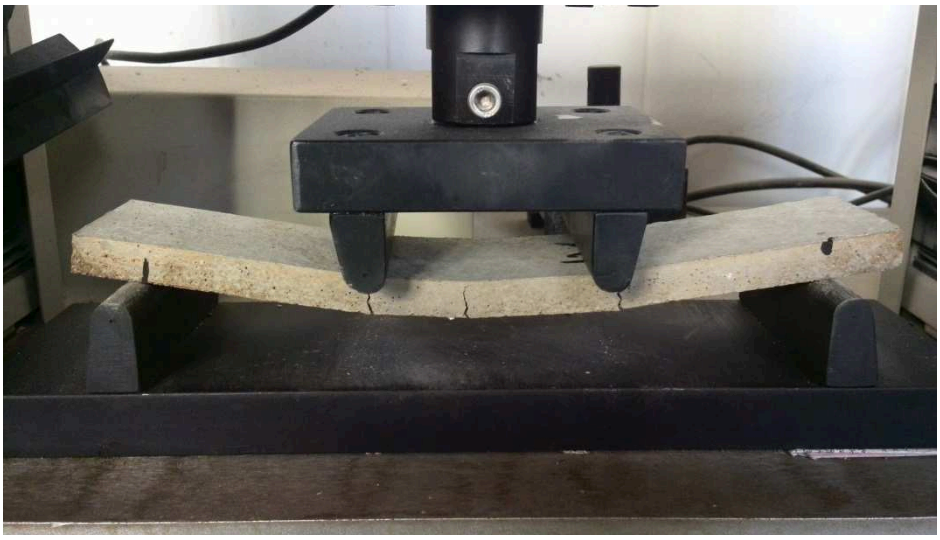

Figure 4. *Flexural strength testing*

Impact strength test
Impact strength tests are carried out by an XCJ-50 Charpy impact machine. The impact energy are recorded, as shown in Figure 5.

Figure 5. *Impact strength testing*

Freezing-thaw cycle resistance
GRC samples are removed from ageing condition and put into the water for 1 day at 20℃. Then freeze the samples for 2 hours at -20℃ and thaw them for an hour at 20℃ as a cycle. We test the mechanical properties of GRC samples after 25 cycles.

Accelerated ageing testing
In line with the experimental program, some samples are stored in a natural environment in Beijing while other samples are placed in 50℃ water. After the specified ageing time is reached, the test samples are taken from the ageing environment, then the flexural and impact strength tests are carried out.

Observation of glass fiber surface
A broken sample is placed immediately in pure alcohol. Prior to observation a surface layer of GRC is removed and a small sample is taken. The surface needs to be fresh and contain cement hydration products and glass fiber. The surface of the sample is studied by scanning electronic microscopy.

RESULTS AND DISCUSSION

The test results of flexural and impact strength of GRC samples are shown in Table 5.

Table 5. *Mechanical properties of GRC samples*

Analysis of flexural strength of GRC
From Table 5 we can find that the LOP and MOR values of GRC samples have the similar change rules:

1) The glass fiber mesh has a much higher reinforcement efficiency then the chopped glass fiber at the same glass fiber ratio. This phenomenon is not obvious when the ratio is low, but it will be very obvious when the ratio is high. S4 and S5 have the similar glass fiber ratio, but the LOP and MOR values of S4 grow up about 1.64% and 6.08% than S1 while the LOP and MOR values of S5 grow up 69.20% and 82.30% than S1, reach the requirements of JC/T 1057-2007 *Glass fiber reinforced cement panel for exterior wall* (LOP≥7.0, MOR≥18.0).
2) When we use the 3D glass fiber fabric as the reinforcement material, the LOP and MOR values of S7 increased sharply to 15.48MPa and 34.68MPa.

The destruction forms of GRC samples can be divided to single crack and multiple cracks. The destruction form of S1 and S2 are single crack, as shown in Figure 6, while the destruction form of S3- S7 are multiple cracks, as shown in Figures 7 and 8.

Figure 6. *Single crack of GRC sample*

Figure7. *Double cracks of GRC sample*

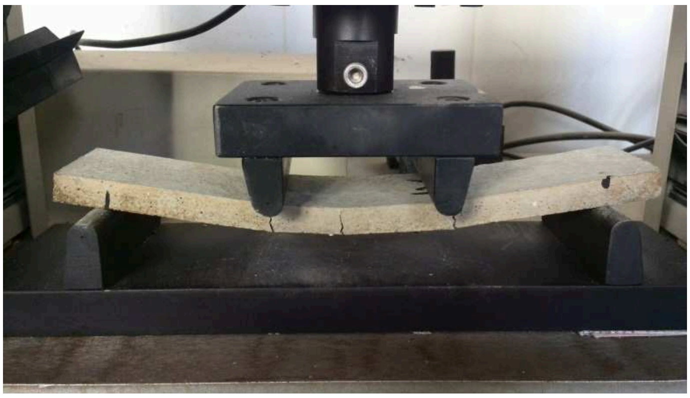

Figure 8. *Multiple cracks of GRC sample*

As cement mortar is a kind of brittle material, S1 breaks very quickly during the tensile strength test. We can find an obvious crack in the bottom of the GRC sample and the damage only happens in this crack. The section of the broken sample S1 is very smooth.
The glass fiber added into S2 is chopped glass fiber and its elastic modulus is 72GPa and tensile strength is 1700MPa while the elastic modulus and tensile strength of cement mortar are only 23.8GPa and 2.4MPa. The chopped glass fiber can combined with the cement

mortar very well to form a random space net system to prevent the micro-crack happen in the cement mortar and reduce the crack number and make the crack smaller. When the load is over the glass fiber's tensile strength, the glass fiber will break or be pulled out of the cement mortar. The section of the broken sample S2 is not smooth and we can see some chopped glass fiber.

The reinforcement material in S3-S6 is glass fiber mesh, which is continuous and warp fiber is parallel to the stress direction. As the elastic modulus and tensile strength of glass fiber mesh are much bigger than the chopped glass fiber, the mesh could bear the stress after the cement mortar broken, we could also find double cracks or multiple cracks in the GRC sample. The single layer mesh would bear the most stress when it is fixed near the bottom surface. When the double layer meshes are fixed near the upper and bottom surfaces, during the tensile strength testing, the bottom layer mesh would bear the tension stress and the upper layer mesh would bear the pressure stress at first. When the load is increasing, the sample begin to strain and both the upper and bottom layer meshes bear the tensile strength which can improve the tensile strength a lot.

The reinforcement material in S7 is 3D glass fiber fabric. At the beginning of the tensile strength test, the stress increases linearly with the strain, then appears a nonlinear section when we can hear the damage voice of the bottom surface and find some cracks in the GRC sample. The bottom layer of the fabric begin to bear the most tensile strength. As the stress increasing, the stem fiber between the upper and bottom layers begin to bear the shearing stress and transfer the stress between the upper and bottom layers. Part of the stem fibers would lean and the combination part between stem fiber and bottom layer begin to break, we can find cracks inside the cement mortar. The bottom layer of the fabric break and the stem fiber also break when the stress get the peak point and the upper layer of the fabric begin to bear the stress, the sample has not broken completely. When the strain increases, the upper layer of the fabric break and the sample break completely. The reinforcement efficiency of 3D glass fiber fabric is much higher than the double layer glass fiber mesh.

Analysis of impact strength of GRC
From Table 5 we can find that the impact strength of GRC sample improve much more obviously than the tensile strength. The glass fiber ratio of S2 and S3, S4 and S5 are similar, but the impact strength improved 45.41% and 200.46%, 240.37% and 560.09% than S1. So the glass fiber mesh can improve the impact strength much higher than the chopped glass fiber. The impact strength of S5 and S6 with double layer mesh are 14.39 KJ/ and 17.13 KJ/ which meet the requirement of JC/T 1057-2007《Glass fiber reinforced cement panel for exterior wall》(impact strength≥8.0 KJ/). The impact strength of S7 with 3D glass fiber fabric improves sharply to 45.04 KJ/ which is 20.66 times of S1. This is because the 3D glass fiber fabric has a good whole performance in the cement mortar. The stem fiber can reduce the crack and enhance the continuity of the reinforcement material to provide the good shearing stress and absorb more energy during the damage process.

Analysis of freezing-thaw cycle resistance of 3D-GRC

The mechanical properties of S7 before and after the freezing-thaw cycle are shown in Table 6.

Table 6. *Freezing-thaw cycle resistance of 3D-GRC*

From Table 6 we can find that the strength loss of LOP, MOR and impact strength of S7 are 1.74%, 1.82% and 3.73%. There is no crack, spall or delamination in the GRC samples. The interface between the glass fiber and cement mortar is easy to destroy during the freezing-thaw cycle which would reduce the mechanical properties of GRC samples. But the 3D glass fiber fabric has good whole performances and the stem fiber can provide the good shearing stress and absorb more energy which makes the strength loss little.

Analysis of accelerated ageing testing of 3D-GRC

The mechanical properties of 3D-GRC samples stored in a natural environment in Beijing or in 50℃ water are shown in Figures 9 to 11. When the specified ageing time is reached, the test samples are taken from the ageing environment, then the flexural and impact strength tests are carried out.

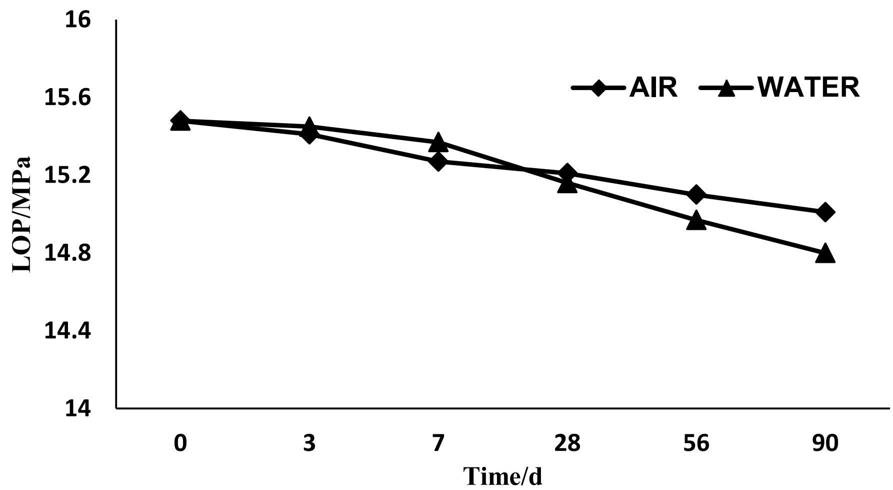

Figure 9. *LOP of 3D-GRC samples after accelerated ageing test*

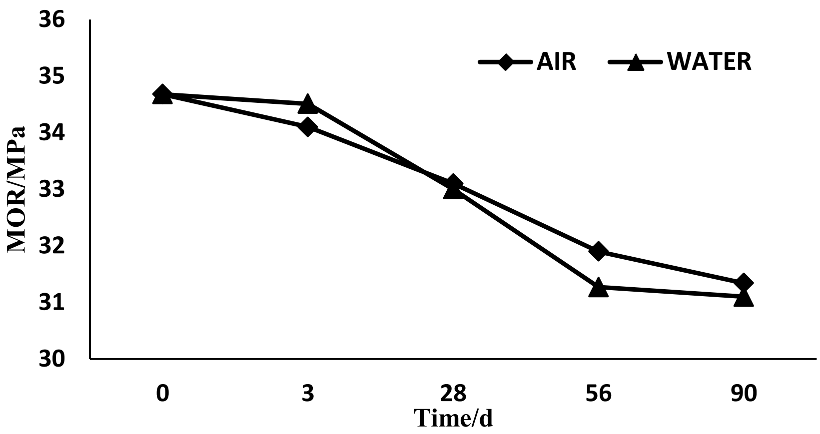

Figure 10. *MOR of GRC samples after accelerated ageing test*

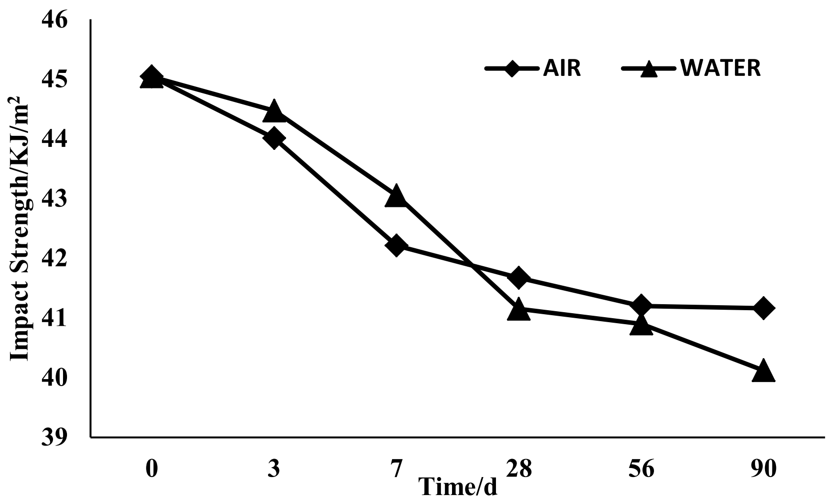

Figure 11. *Impact strength of GRC samples after accelerated ageing test*

From Figures 9 to 11 we can find that both the tensile and impact strength values decline by time no matter exposed in air or hot water at 50℃. The mechanical properties of GRC samples in hot water are higher than the ones in air during the early time because the cement particles in hot water continue hydration reaction which results in increased mechanical properties of the samples. As the ageing time going on, the mechanical properties of GRC samples in hot water are lower than the ones in air because the hot water accelerate the damage of glass fiber caused by the cement mortar. After ageing in air for 90 days, the retention ratios of LOP, MOR and impact strength values are 96.96%, 90.37% and 91.41%. After ageing in hot water for 90 days, the retention ratios of LOP, MOR and impact strength values are 95.61%, 89.68% and 89.14%. The retention ratios of mechanical properties of GRC samples in air are closed to the ones in hot water, both are about 90%, which meant that GRC samples had excellent ageing properties. This is because the AR-glass fiber's ZrO2 content is 16.7% which is better than the E-glass fiber. On the other hand, the 3D glass fiber fabric still has good whole performance after the accelerated ageing testing.

Observation of glass fiber surface

The surfaces of glass fiber subjected to different ageing conditions are observed by scanning electron microscopy and are shown in Figures 12 to 14.

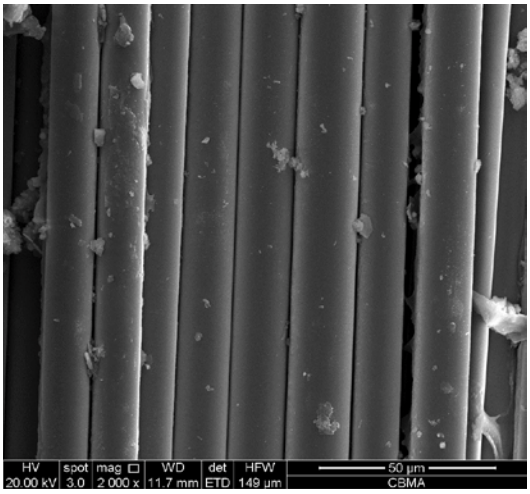

Figure 12. *3D-GRC (standard cure, 3 days)*

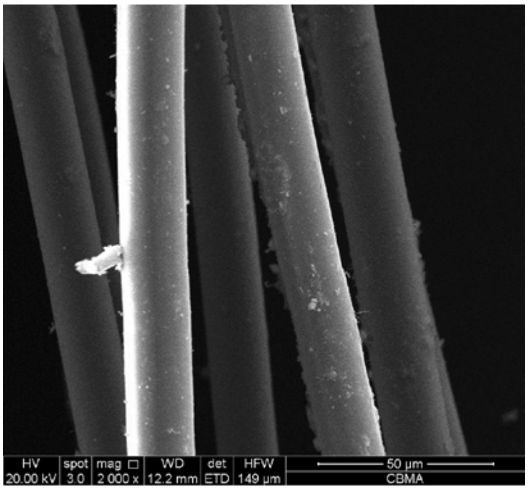

Figure 13. *3D-GRC (in air, 90 days)*

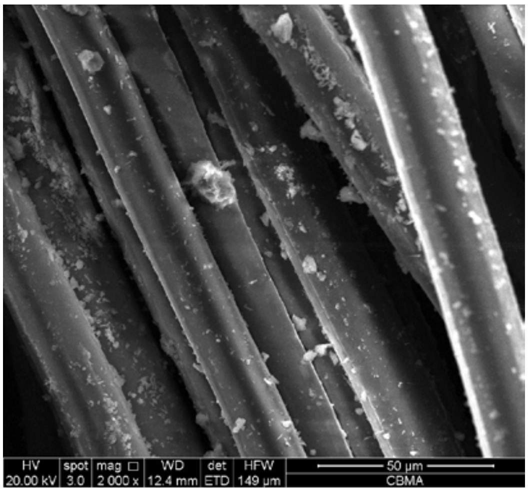

Figure 14. *3D-GRC (in hot water at 50℃, 90 days)*

From Figures 12 to 14 it can be seen that for a standard 3 days curing, the outline of glass fiber is very clear and its surface has a few attachments. However, for GRC samples aged in air and hot water at 50℃ for 90 days, the outline of glass fiber is different. The surface of glass fiber is still smooth for the samples in air whereas the surface of glass fiber has visible corrosion marks for the samples in hot water. This microscopic analysis result supports the test results for mechanical properties.

CONCLUSIONS

1) The glass fiber mesh has a much higher reinforcement efficiency then the chopped glass fiber at the same glass fiber ratio because the mesh is continuous and warp fiber is parallel to the stress direction. As the elastic modulus and tensile strength of glass fiber mesh are much bigger than the chopped glass fiber, the mesh could bear the stress longer after the cement mortar broken.
2) 3D-GRC samples have good mechanical properties because the 3D glass fiber fabric has a good whole performance in the cement mortar. The stem fiber can reduce the crack and enhance the continuity of the reinforcement material to provide the good shearing stress and absorb much more energy during the damage process.
3) The 3D-GRC samples have good freezing-thaw cycle resistance. The retention ratio of properties are under 5% after 25 cycles because the stem fiber can bear more shearing stress, transfer the stress between bottom and upper layer and absorb energy which makes the strength loss little.
4) The test results of GRC samples subjected to accelerated ageing in 50℃ water indicated that the retention ratio of mechanical properties is similar to the GRC samples retained in a natural environment in Beijing.

Acknowledgements

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