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The influence of component change of raw materials on GRC durability

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Summary

In this paper the durability of glassfibre-reinforced concrete (GRC) made with three kinds of sulphoaluminate cement and combined with two kinds of alkali-resistant (AR-)glassfibre respectively is reported. The main factors affecting the performance of GRC were observed through analysing the regularity of flexural strength and impact strength of control GRC samples aged in a natural environment and samples subjected to accelerated aging in 80°C water or 50°C water. Experimental results indicate that the long-term durability of GRC is mainly increased by the type of AR-glassfibre used .

Key words: early-strength sulphoaluminate cement, low-alkali sulphoaluminate cement, compound sulphoaluminate cement, alkali-resistant glassfibre, flexural strength, impact strength

1. Introduction

Practical application over 30 years has proved that the technology of applying alkali-resistant (AR-)glassfibre combined with sulphoaluminate cement is feasible and contributes to the long-term performance of glassfibre-reinforced cement (GRC) in China. Ongoing technological R&D has meant that compound sulphoaluminate cement has been available on the market, and the content of ZrO2 in AR-glassfibre has risen to 16.7%. As the principal raw materials, any change in the AR-glassfibre and sulphoaluminate cement components will affect long-term performance.

Respective mixes of three kinds of sulphoaluminate cement and two kinds of AR-glassfibre formed six GRC formulations. The main factors which affect performance of GRC can be observed by testing the flexural strength and impact strength of GRC in a natural environment and also subjected to accelerated aging in either 80°C or 50°C water.

It is expected that the mechanical property and durability of different formulations of GRC can be defined by this experiment, in order to offer a technical basis for development of GRC.

2. Raw materials and formulation

Cement: 42.5 grade early-strength sulphoaluminate cement, 32.5 grade low-alkali cement and 32.5 grade compound sulphoaluminate cement; the main mineral components of these three types of cement are listed in Table 1.

Kinds of sulphoaluminate	Dosage of blending material			pH value in liquid phase
	Gypsum	Limestone	ggbs	
Early-strength (code name: KY)	Suitable	≤ 15% cement mass	--	10.8–11.3
Low-alkali (code name: DJ)	Suitable	≥ 15% cement mass and ≤ 35% cement mass	--	< 10.5
Compound (code name: FH)	≤ 20% cement mass			11.2–11.6

Table 1. Mineral components of the three cement types

Glassfibre: two kinds of AR-glassfibre are used; their ZrO_2 content is 14.5% or 16.7% respectively; their mechanical properties are listed in Table 2.

Glassfibre type	Modulus of elasticity (GPa)	Tensile strength (MPa)	Elongation (%)
ZrO_2 content 14.5% (code name: M)	63–70	1700	4.0
ZrO_2 content 16.7% (code name: N)	72–80	1800	2.4

Table 2. Mechanical properties of alkali-resistant glassfibre

Sand: River sand, maximum particle diameter no larger than 2 mm; fines content no greater than 2%.

Admixture: Superplasticiser.

Water: Tap water.

Three kinds of cement were combined with two kinds of glassfibre respectively to form six GRC formulations: KY-M, KY-N, FH-M, FH-N, DJ-M and DJ-N (see codes in above tables); cement/sand ratio was 1:1; water/cement (w/c) ratio was 0.35 for all formulations; the dosage of glassfibre was 5% of the mass of mortar; fluidity of mortar was 110–115 mm which is controlled by adjusting the admixture dosage.

For each formulation, several GRC sample panels were prepared by the spray method. The size of each panel was 800 × 600 ×10 mm. After curing was completed, GRC test pieces were cut from these panels. The size of samples for flexural testing was 250 × 50 × 10 mm; the size for the impact test was 120 × 50 × 10 mm. These sample pieces were divided into groups, each group comprising ten pieces for flexural testing and ten pieces for impact testing.

In line with the experimental programme, some groups were stored in a natural environment in Beijing while other groups were placed in 80°C or 50°C water. After the specified aging time was reached, the test pieces were taken from the aging environment, placed for 24 h in room conditions, then the flexural and impact tests were carried out.

Flexural strength. The GRC samples were removed from the aging condition, dried for three days at room temperature, then flexural testing was carried out by use of a WD4100 electronic testing machine, in third-point loading with a span of 210 mm and loading speed of 5 mm/min. The limit of proportionality (LOP) and modulus of rupture (MOR) were recorded.

Impact strength. The GRC samples were removed from the aging condition, dried for three days at room temperature, then impact testing was carried out with an XCJ-50 Charpy impact machine. The impact energy was recorded.

3. Test results and analysis of mechanical properties

3.1. Mechanical property of GRC in natural environment

Test results of the flexural strength of GRC in natural conditions in Beijing are listed in Table 3. Figure 1 shows the change of flexural strength with aging time.

Aging Time (days)	KY-M		KY-N		FH-M		FH-N		DJ-M		DJ-N	
	LOP	MOR	LOP	MOR	LOP	MOR	LOP	MOR	LOP	MOR	LOP	MOR
0	8.1	18.3	9.1	19.6	8.9	18.4	10.6	20.0	9.8	18.0	10.1	21.3
28	7.8	17.2	8.2	19.6	8.1	16.9	7.8	19.7	8.2	17.9	8.2	20.8
56	7.7	15.8	8.5	18.3	7.9	16.1	7.2	18.8	7.6	16.3	8.1	19.5
90	9.0	16.4	9.8	18.4	9.2	17.0	9.0	18.8	9.0	15.8	9.8	19.9
180	8.5	15.3	10.3	18.1	8.3	15.3	8.5	18.8	9.0	15.8	9.9	20.8
Note: Aging time means time aging in natural environment after standard seven-day curing.												

Table 3. Test results of flexural strength of GRC in natural environment

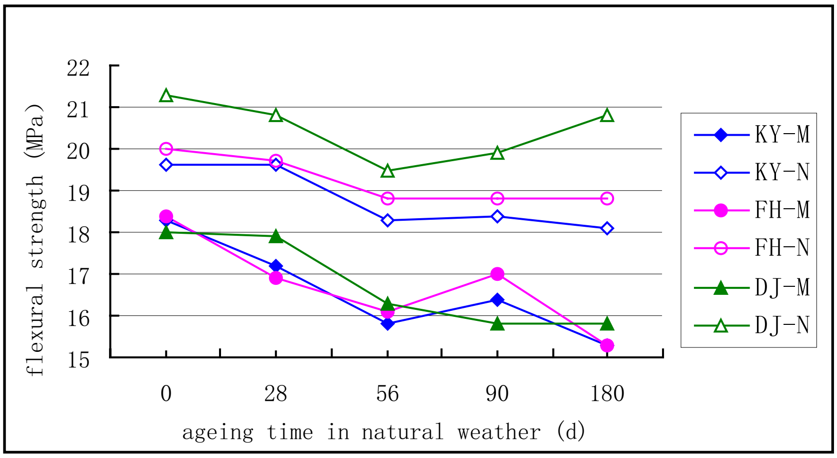

Figure 1. Flexural strength VS aging time

It can be seen from Table 4 and Figure 1 that the flexural strength of all formulations of GRC follow the same trend, namely that GRC with higher ZrO_2 content exhibits higher flexural strength. This demonstrates the effect of increasing glassfibre ZrO_2 content and shows that 16.7% is better than 14.5%. This is attributed to the relatively higher modulus of elasticity of glassfibre with 16.7% ZrO_2.

When GRC samples are stored in a natural environment for 180 days, retention of the flexural strength of GRC made from early-strength cement and M-type glassfibre is 83.6% whereast that of GRC made from N-type glassfibre is 92.3%. Retention of the flexural strength of GRC made from compound cement and M-type glassfibre is 83.2% whereas that made from N-type glassfibre is 94.0%. Retention of the flexural strength of GRC made from low-alkali cement and M-type glassfibre is 87.8% whereas that of GRC made from N-type glassfibre is 97.7%. These results indicate that the durability of glassfibre with 16.7% ZrO_2 is better than the durability of glassfibre with 14% ZrO_2.

Table 4 lists the test results of GRC impact strength for different ageing times in a natural environment.

Ageing time (days)	KY-M	KY-N	FH-M	FH-N	DJ-M	DJ-N
0	14.7	15.3	16.0	17.2	15.6	17.9
28	14.2	14.7	14.9	16.3	14.3	17.4
56	13.8	14.1	16.0	16.4	14.7	18.0
90	14.9	14.9	15.7	15.9	14.7	17.5
180	14.3	14.8	15.3	15.3	14.1	16.7
Note: Aging time means time aging in natural environment after standard seven-day curing.						

Table 4. Test results of GRC impact strength in natural environment

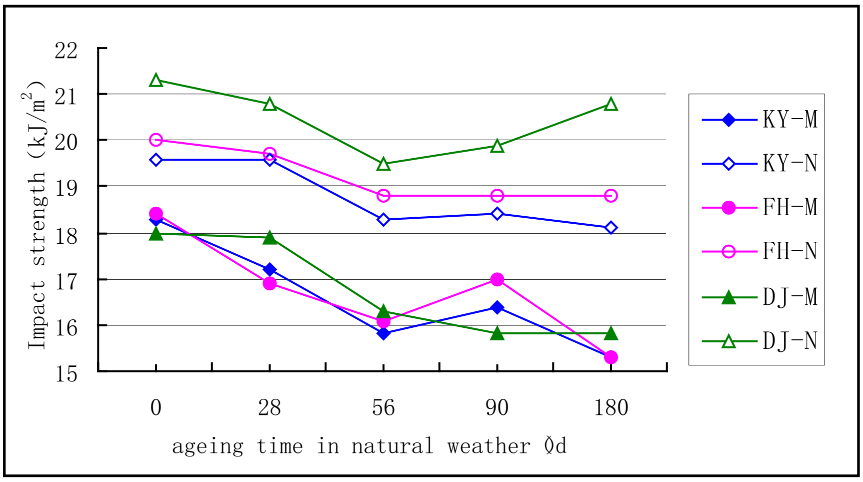

Figure 2. Impact strength VS aging time

It can be seen from Table 4 and Figure 2 that the pattern of impact strength of GRC is the same as for flexural strength, whichever cement is combined with glassfibre; however, GRC using higher ZrO_2 glassfibre exhibits higher impact strength.

3.2. Mechanical property of GRC accelerated ageing in 80°C water

Test results for flexural strength of GRC aged in 80°C water are listed in Table 5.

Ageing time (days)	KY-M		KY-N		FH-M		FH-N		DJ-M		DJ-N	
	LOP	MOR	LOP	MOR	LOP	MOR	LOP	MOR	LOP	MOR	LOP	MOR
0	8.1	18.3	9.1	19.6	8.9	18.4	10.6	20.0	9.8	18.0	10.1	21.3
3	8.7	18.5	10.5	19.7	8.4	16.5	9.7	19.4	8.9	17.0	9.8	19.7
7	9.2	16.5	10.7	18.9	10.2	17.5	9.0	20.2	9.1	15.9	9.4	20.8
14	9.5	16.5	10.1	16.6	8.3	15.5	9.3	17.2	9.1	15.0	8.8	17.4
21	8.2	14.2	8.0	15.7	7.7	15.0	7.9	16.6	8.3	14.2	9.1	15.9
28	8.5	15.1	9.0	16.5	7.0	13.8	7.7	14.7	8.2	13.9	9.6	16.1
35	10.3	15.5	9.9	15.2	8.3	13.9	9.2	14.5	9.8	12.8	10.0	16.5
42	9.2	13.7	8.9	14.8	7.9	13.1	9.1	15.5	8.9	14.0	8.3	16.1
Note: Aging time means time aged in 80°C water after standard seven-day curing.												

Table 5. Test result of flexural strength of GRC aged in 80°C water

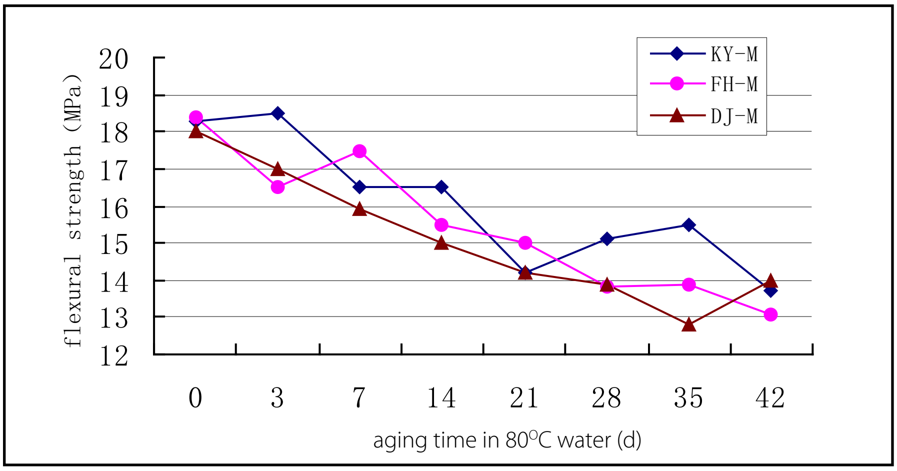

Figure 3. Flexural strength VS aging time

It can be seen from Table 5 that although the GRC samples have been aged in 80°C water for 42 days, both their absolute flexural strength and retention of strength show the beneficial effect of sulphoaluminate cement with AR-glassfibre. If absolute flexural strength is considered, the flexural strength of aged GRC is still far higher than its LOP, which indicates that glassfibre has an increasing effect. If retention of strength is considered, retention of KY-M GRC is 74.9%, KY-N is 75.5%, FH-M is 71.2%, FH-N is 77.5%, DJ-M is 77.8% and DJ-N is 75.6%.

Figures 3 and 4 indicate that there are no obvious differences from the effect of sulphoaluminate cement type on flexural strength and retention of strength.

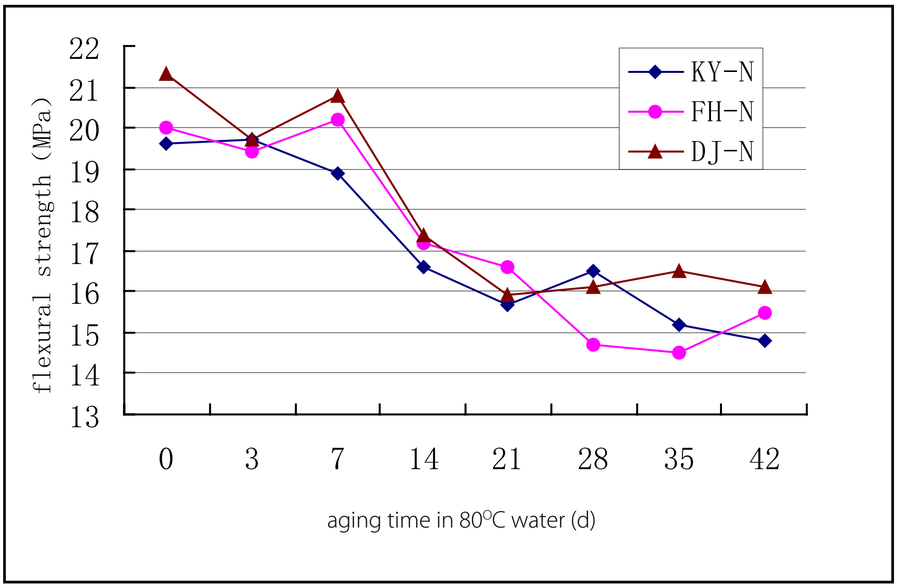

Figure 4. Flexural strength VS aging time

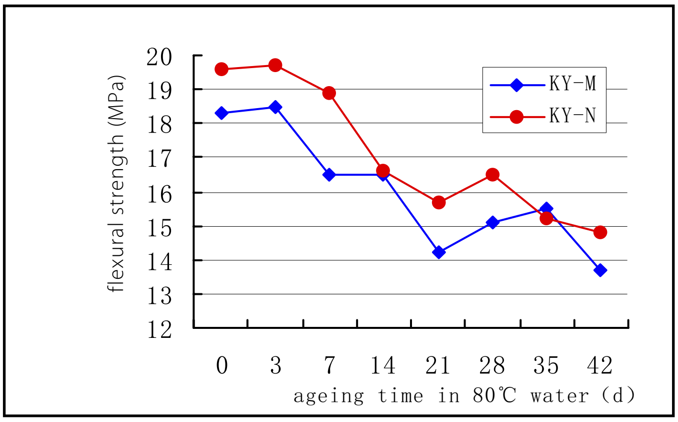

Figure 5. Flexural strength VS aging time

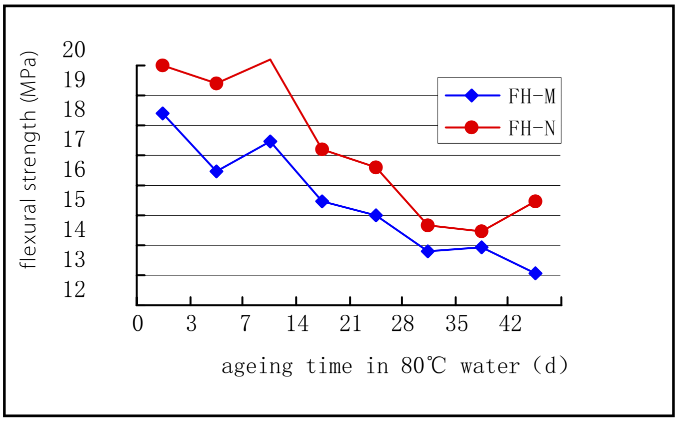

Figure 6. Flexural strength VS aging time

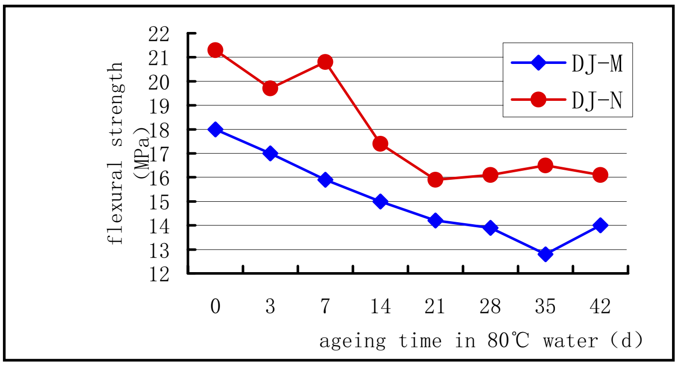

Figure 7. Flexural strength VS aging time

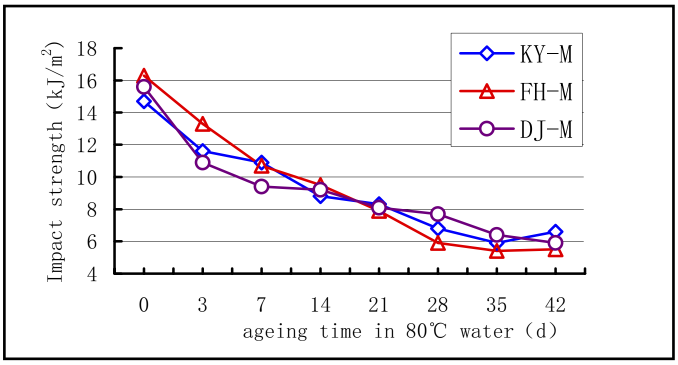

Figure 8. Flexural strength VS aging time

Figures 5–7 indicate that when using the same kind of sulphoaluminate cement, there is a greater influence of glassfibre type on flexural strength, and an obvious effect of glassfibre on retention of strength.

Test results for impact strength of GRC aged in 80°C water are listed in Table 6.

Ageing time (days)	KY-M	KY-N	FH-M	FH-N	DJ-M	DJ-N
0	14.7	15.3	16.3	17.2	15.6	17.9
3	11.6	13.0	13.3	14.6	10.9	15.1
7	10.9	12.7	10.7	13.3	9.4	13.9
14	8.8	10.2	9.5	10.9	9.2	10.6
21	8.3	8.5	7.9	9.3	8.1	8.1
28	6.8	7.0	5.9	8.5	7.7	7.3
35	5.9	7.2	5.4	7.5	6.4	8.3
42	.6	8.0	5.5	8.0	5.9	8.1
Note: Aging time means time aging in 80°C water after standard seven-day curing.						

Table 6. Test results for impact strength of GRC aged in 80°C water

From Table 6, for GRC samples aged in 80°C water for 42 days, the retention of impact strength of KY-M is 44.9%, that of KY-N is 52.3%, that of FH-M is 33.7%, that of FH-N is 46.5%, that of DJ-M is 37.8% and that of DJ-N is 45.3%. It is concluded from this that, despite aging of GRC in hot water for 42 days, GRC retains higher toughness and very much higher impact strength compared with plain mortar. From Figures 8 and 9 the decreasing rate of change of impact strength can be observed. The impact strength for all formulations of GRC decreases more quickly up to age 28 days, and for 28-day and 45-day aged GRC the impact strength tends towards stability .

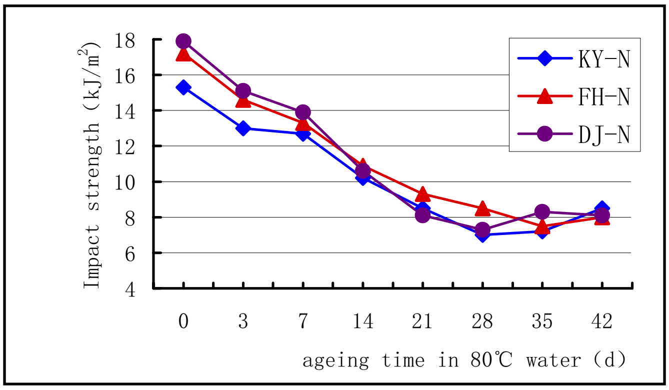

Figure 9. Flexural strength VS aging time

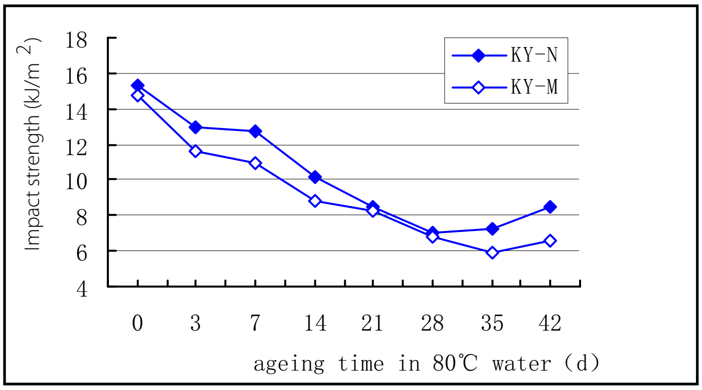

Figure 10. Flexural strength VS aging time

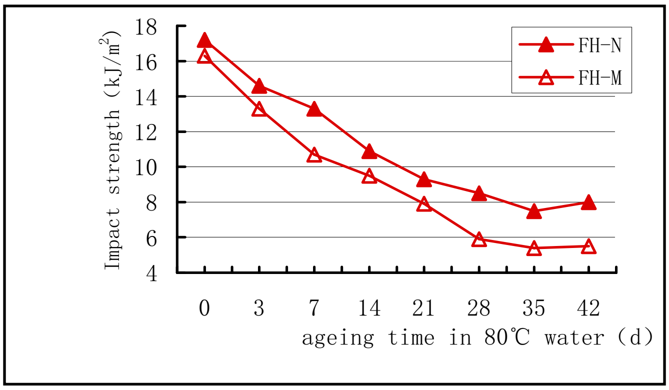

Figure 11. Flexural strength VS aging time

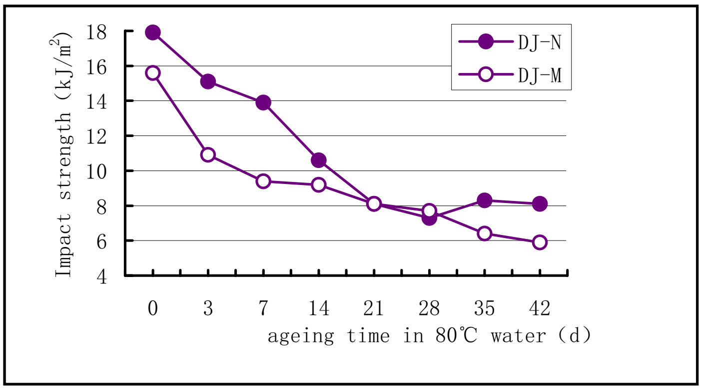

Figure 12. Flexural strength VS aging time

It can be seen from Figures 10–12 that whichever sulphoaluminate cement is used, the impact strength of GRC with higher ZrO_2 glassfibre content is higher than that with lower ZrO_2 glassfibre content, both before and after aging. It can be deduced from this that the former has a better effect on toughness than the latter.

3.3. Mechanical properties of GRC subjected to accelerated ageing in 50°C water

Test results for the flexural strength of GRC aged in 50°C water are listed in Table 7.

Ageing time (days)	KY-M		KY-N		FH-N		DJ-N	
	LOP	MOR	LOP	MOR	LOP	MOR	LOP	MOR
0	8.1	18.3	9.1	19.6	10.6	20.0	10.1	21.3
3	9.6	16.8	11.0	20.7	11.0	20.5	9.5	20.7
7	10.9	18.6	11.2	20.3	9.8	18.9	10.2	21.2
14	8.0	16.5	8.9	20.0	9.2	18.6	9.1	20.7
21	8.7	15.8	8.8	19.9	9.6	17.6	9.3	20.0
28	8.0	15.5	9.5	19.2	7.8	17.1	8.6	19.2
56	8.4	15.1	11.3	17.5	8.7	18.1	10.0	20.0
90	10.9	16.6	13.2	17.9	9.5	18.0	10.4	19.0
Note: Aging time means time aging in 50°C water after standard seven-day curing.								

Table 7. Test results for flexural strength of GRC aged in 50°C water

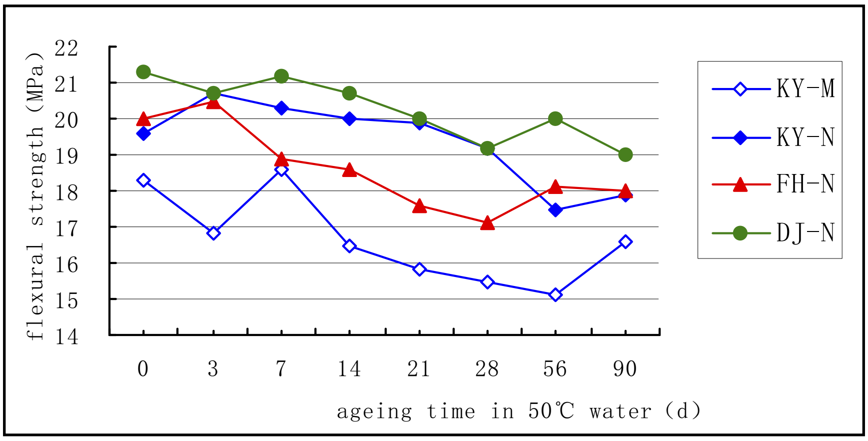

Figure 14. Flexural strength VS aging time

From Table 7 it can be seen that when GRC was aged in 50°C water for 90 days, the flexural strength retention of KY-M was 90.7%, that of KY-N was 91.3%, that of FH-N was 90.0% and that of DJ-N was 89.2%. These results are slightly lower than the results for GRC of the same formulation in a natural environment, which indicates that the ageing rate in 50°C water is very slow.

Aging time (days)	KY-M	KY-N	FH-N	DJ-N
0	14.7	15.3	17.2	17.9
3	13.0	13.9	14.4	14.5
7	12.8	13.7	14.4	14.9
14	11.4	12.7	14.3	14.4
21	11.0	13.2	14.0	15.0
28	10.3	12.7	13.6	14.2
56	8.7	10.2	11.9	12.5
90	8.8	10.3	11.3	12.3
Note: Aging time means time aging in 50°C water after standard seven-day curing.				

Table 8. Impact strength of GRC aged in 50°C water

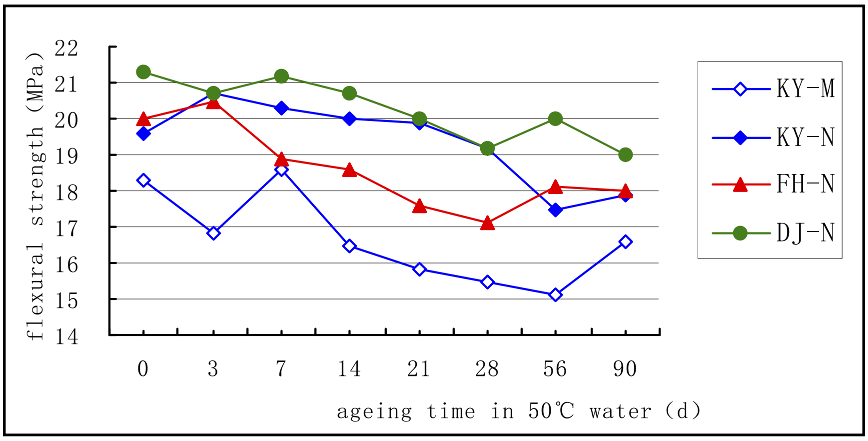

Figure 14. Flexural strength VS aging time

4. Microscopic analysis result

The surface of glassfibre subjected to different aging conditions was observed by scanning electron microscopy and is shown in Figures 15–18.

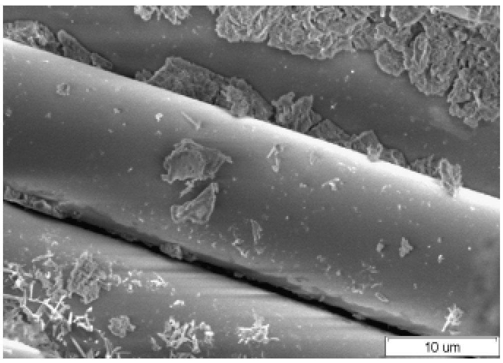

Fig.15. DJ-N GRC(standard cure,7day)

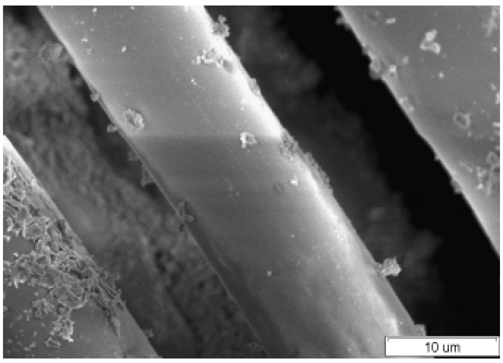

Fig.16. DJ-M GRC(standard cure,7 day)

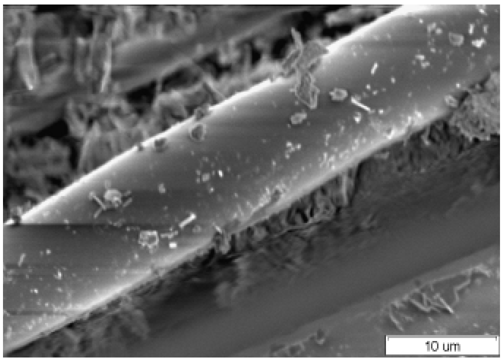

Fig.17. DJ-N GRC(in 80, water,39day)

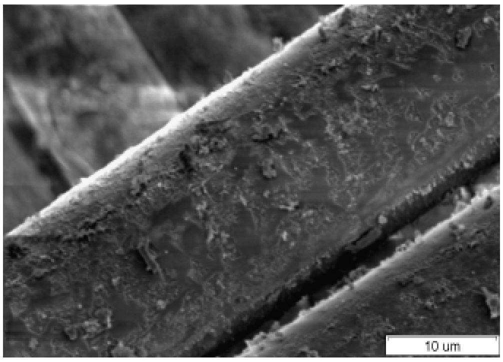

Fig.18. DJ-M GRC(in 80, water,39day)

From Figures 15–18 it can be see that for a standard 28-day curing, the outline of fibre is very clear and its surface has a few attachments, for both N-type and M-type glassfibre. However, for GRC aged in 80°C water for 39 days, the outline of each type of glassfibre was obviously different. The surface of N-type glassfibre was still smooth whereas the surface of the M-type glassfibre had visible corrosion marks. This microscopic analysis result supports the test results for mechanical properties.

5. Conclusions

GRC samples subjected to accelerated testing in 80°C water indicated the following:

1. The influence of cement component change on GRC flexural strength, impact strength and long-term performance is not marked, and there is no clear regularity.
2. The influence of AR-glassfibre component change on GRC mechanical property and durability was distinctly different: the reinforcement effect of glassfibre with higher ZrO_2 content is better than glassfibre with lower ZrO_2 content.

The test results of GRC samples subjected to accelerated aging in 50°C water indicated that at early stages the reducing rate of GRC strength is not noticeably different compared with the control GRC samples retained in a natural environment in Beijing. Further studies are required to validate the effect.