MECHANICAL PROPERTIES OF FIBER REINFORCED GEOPOLYMER MORTAR AND CONCRETE

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1. INTRODUCTION

According to the effect of global warming, scientists and engineers have been continuously paying attention to eco-friendlier construction materials. A new kind of concrete: geopolymer concrete, which can be referred to as amorphous alkali aluminosilicate or alkali-activated cement, will not leak much carbon dioxide during casting compared to the ordinary cement concrete. Geopolymer concrete can be produced by polymerizing the aluminosilicates such as fly ash, metakaolin, slag, rice husk ash and high calcium wood ash through activation using alkaline solution.

In this research, a specific kind of pre-mixed geopolymer binder was used and investigated. The pre-mixed geopolymer binder is made of a high-performance fiber reinforced geopolymer binder specifically engineered for rehabilitating pipes, culverts and containment areas. And it has not been widely used as a construction material in construction sites. Therefore, the objective of this research is to investigate the mechanical properties of a specific kind of geopolymer mortar and concrete using the fiber reinforced geopolymer binder as the original material.

2. EXPERIMENTAL PROGRAM

Experimental methods which are compressive strength cylinder test, splitting cylinder test and three-point bending test using notched beam were conducted to investigate the mechanical properties of the geopolymer fabricated mortar and concrete. Compressive strength cylinder test was carried out according to JIS A 1108 "Method of test for compressive strength of concrete"; splitting cylinder test was carried out according to JIS A 1113 "Method of test for splitting tensile strength of concrete"; notched beam test was carried out according to JCI-S-001-2003 "Method of test for fracture energy of concrete by use of notched beam". **Table 1** gives the different mix proportions in each case. **Table 2** gives the diameter of each cylinder used in the experiments. The dimension of the notched beam was 100×100×400mm, and the width and depth of notch were 5mm and 30mm.

As **Table 1** shows, 7 cases were chosen. CC57 stands for the ordinary cement concrete where the water/cement ratio is 57%. GC57 stands for the geopolymer concrete of which cement was directly replaced by pre-mixed geopolymer binder which consists of aluminosilicates, alkali-activator, sand and short fiber. GC20 stands for the geopolymer concrete of which the W/B value was 20% and, in this case, the same volume of water plus geopolymer was used to replace that of water plus cement plus sand in CC57 case. PGC20 means the prepacked geopolymer concrete of which the W/B value was 20% and only large aggregate was used in this case. As an explanation, prepacked geopolymer concrete was fabricated by the following method: firstly put the aggregate into the mold or formwork and fulfill it and then pour the geopolymer mortar to make the concrete. M15, M20 and M30 mean geopolymer binder mixed only with water and the W/B value is 15%, 20% and 30%.

All the specimens were cured in the same condition, which was 20 degrees centigrade and being covered by wet clothes, and curing time was chosen to be 7, 14 and 28 days.

Table 1 Mix proportions

Name	Unit weight (kg/ m³)					
	W	B	S	SG	LG	AD
CC57	172	301	785	515	515	3
GC57	172	301	726	476	476	3
GC20	165	825		515	515	
PGC20	141	703			1362	
M15	234	1559				
M20	289	1446				
M30	379	1263				

W: Water, B: Binder (Cement or Geopolymer Binder), S: Sand, SG: Small Aggregate (5mm~13mm), LG: Large Aggregate (13mm~20mm), AD: Admixture

Table 2 Size of cylinders

Name	Diameter(mm)	Height (mm)
Compressive cylinder for mortar/concrete	50 / 100	100 / 200
Splitting cylinder	100	100~150

3. EXPERIMENTAL RESULTS

(1) Cylinder tests

Three W/B ratios 15%, 20% and 30% were chosen to test the relatively appropriate value for geopolymer mortar. As an experimental result, the geopolymer mortar was quite sensitive to water, and three geopolymer mortar showed different characteristics. In the 30% W/B case, even after enough mixing time, the segregation occurred and still some materials remained at the bottom of the bucket. While in the 15% W/B case, the mortar was quite hard to mix. And the 20% W/B case showed a balance between workability and strength. Through a series of compressive strength cylinder tests, the results are listed in **Table 3**. It can be obviously seen that in the case GC57, very weak strength was observed, which is to say the direct replacement of cement with pre-mixed geopolymer binder is not feasible.

Similar to ordinary cement concrete, as W/B ratio decreased, the strength of geopolymer fabricated mortar and concrete increased. Furthermore, even within the same W/B ratio as in the case of GC20, PGC20 and M20, the increase in the compressive strength of concrete almost finished in

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14 days, while the strength increase of mortar continued till 28 days.

Table 3 Compressive strength results

Name	Compressive strength (MPa)		
	Curing time (days)		
	7	14	28
CC57	16.7		27.6
GC57	1.8		3.8
GC20	36.2	52.8	48.9
PGC20	30.6	40.6	41.3
M15	52.3	68.3	72.9
M20	29.1	43.8	51.1
M30	17.2	31.8	34.0

Table 4 Tensile strength results

Name	Tensile strength (MPa)				Experimental value/Calculated value	
	Experimental value		Calculated value			
	Curing time (days)		Curing time (days)		Curing time (days)	
	7	28	7	28	7	28
CC57	1.6	2.2	1.5	2.1	1.06	1.06
GC20	3.3	4.0	2.5	3.1	1.30	1.31
PGC20	3.1	3.9	2.3	2.8	1.38	1.42
M20	3.3	3.4				

The tensile strength is listed in **Table 4**. For GC20, PGC20 and M20 cases, it can be seen that the tensile strength of concrete at 28 days was 18% and 14% larger than that of mortar, which means the aggregate helps to increase the tensile strength to some extent. Moreover, the calculated tensile strength of each case was obtained by referring to the JSCE standard specifications and compared with experimental values. The Experimental value/Calculated value ratio of geopolymer concrete was larger than that of ordinary concrete. The results revealed that in the cases of geopolymer concrete, the tensile strength was improved by fiber reinforcement to some extent.

Table 5 Young's Modulus results

Name	Young's Modulus (kN/mm^2)					
	Experimental value			Calculated value		
	Curing time (days)			Curing time (days)		
	7	14	28	7	14	28
CC57	23.7		26.3	21.3		26.8
GC20	29.2	32.1	31.8	29.9	33.6	32.8
PGC20	26.6	32.4	31.9	28.2	31.1	31.3

Furthermore, from compressive cylinder tests, the experimental values of Young's Modulus were also obtained. The calculated values were obtained by referring to the JSCE standard specifications. As **Table 5** shows, the experimental values are quite close to the calculated values in all the cases. That is to say, replacing cement mortar within geopolymer mortar to fabricate concrete will not affect the compressive rigidity of concrete.

(2) Notched beam tests

In the notched beam tests, 4 cases which are CC57D7, CC57D28, GC20D28, and PGC20D28 were chosen where D7 and D28 mean the curing time of 7 days and 28 days, respectively. The Load-LPD curves are shown in **Fig. 1**. The fracture energy of four cases was calculated following equations (1) and (2) in the JCI standard: 0.14N/mm, 0.15N/mm 0.19N/mm, and 0.19N/mm. Since the fracture energy is independent of compressive strength in the ordinary cement concrete (J.P. Ulfkjær et al.), the fracture energy of the ordinary cement concrete could be defined as 0.15N/mm which is smaller than 0.19N/mm of the geopolymer concrete. Therefore, the geopolymer concrete is superior to the ordinary cement concrete in terms of fracture energy.

$$G_F = \frac{W_0+W_1}{A_{lig}} \quad (1)$$

$$W_1=\left(\frac{S}{L}m_1+2m_2\right)g\cdot LPD_c \quad (2)$$

Where G_F: fracture energy (N/mm), W_0: area below the load-*LPD* curve up to the rupture of a specimen (N·mm), W_1: work done by the deadweight of a specimen and equipment attached to a specimen (N·mm), A_{lig}: area of the ligament right over the notch (mm^2), S: loading span (mm), L: total length of a specimen (mm), m_1: mass of a specimen (kg), m_2: mass of equipment attached to a specimen (kg), g: gravitational acceleration (9.807 m/s^2), LPD_c: loading point displacement at rupture (mm).

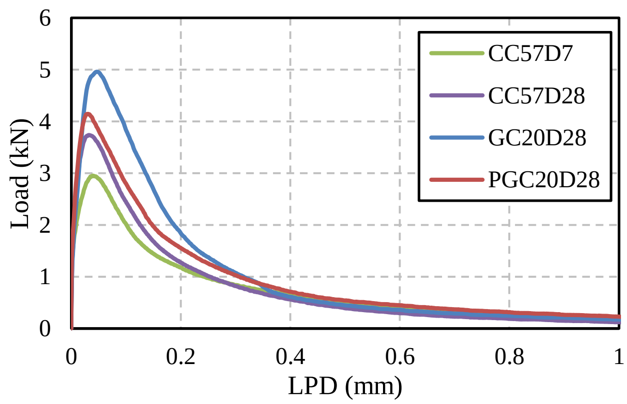

Fig. 1 Load-LPD (Load Point Displacement) curves

4. CONCLUSIONS

(1) When the W/B ratio is around 20%, geopolymer fabricated mortar and concrete could get acceptable mechanical properties compared with ordinary cement concrete.

(2) Further research on the structural performance of the geopolymer concrete is recommended for practical use in construction sites.

5. REFERENCES

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