Coventry University and
The University of Wisconsin Milwaukee Centre for By-products Utilization,
Second International Conference on Sustainable Construction Materials and Technologies
June 28 - June 30, 2010, Università Politecnica delle Marche, Ancona, Italy.
Main Proceedings ed. J Zachar, P Claisse, T R Naik, E Ganjian. ISBN 978-1-4507-1490-7
http://www.claisse.info/Proceedings.htm

Internal Curing Effect of Artificial Lightweight Aggregate on Green Concrete

Wataru Itoh, Kei-Ichi Imamoto, and Akio Tanaka

Dept. of Arch., Tokyo University of Science － 1-14-6 Kudan-kita, Chiyoda-ku, Tokyo 102-0073, JAPAN. E-mail: ＜ito.wat@gmail.com＞, ＜imamoto@rs.kagu.tus.ac.jp＞, ＜at2862@yahoo.co.jp＞.

ABSTRACT

A large amount of carbon dioxide is emitted during the production of ordinary Portland cement. For example, about 800 kg of CO_2 is released during the production of 1 t of ordinary Portland cement that will cause global warming. Hence, the authors propose "green concrete (GC)" that does not use ordinary Portland cement. GC uses a binder comprising pulverized waste plasterboard, blast furnace slag, and fly ash. In this study, the mechanical properties of GC, such as compressive strength and autogenous shrinkage, were compared with those of ordinary Portland cement. It was found that GC exhibits high autogenous shrinkage. To reduce the autogenous shrinkage, GC with an artificial lightweight aggregate (GCL) is also proposed. The autogenous shrinkage of this GC decreased because of the internal curing effect of the aggregate.

INTRODUCTION

In this study, we will discuss the fundamental properties of green concrete (GC) that does not use cement but uses pulverized waste plasterboard, blast furnace slag, and fly ash with an alkaline activator [Imamoto and Yoshiba].

This study has two purposes. The first is to repress global warming. Needless to say, activities that result in the emission of CO_2 contribute to the heating up of Earth. In the architectural and civil engineering industry, it is said that 800 kg of CO_2 is released during the production of 1 t of ordinary Portland cement. Hence, it is necessary to reduce the amount of CO_2 emissions by replacing Portland cement with other environment-friendly binders.

The second purpose of this study is to encourage the recycling of waste plasterboards. In Japan, about 950,000 t of waste plasterboards (WPBs) were discarded during 2000; it is estimated that this value will increase up to 1,080,000 t by 2010. About 40% of WPBs discarded at building construction sites are reused as additives for new plasterboards, soil improvement materials, etc. The effective reuse of WPBs is a matter of social concern in Japan.
In this study, the mechanical properties of GC, such as compressive strength, tensile strength, elastic modulus, creep coefficient, adiabatic temperature rise, autogenous shrinkage, and drying shrinkage, were measured and compared with those of ordinary Portland cement.

Further, the properties of GC with an artificial lightweight aggregate (GCL) were also measured and the internal curing effect of the aggregate was investigated.

OUTLINE OF EXPERIMENTS

Materials and mix proportions used in this study are shown in Tables 1 and 2, respectively. Six mixtures were produced. Pulverized waste plasterboard (PWB), ground granulated blast furnace slag (GGBFS), and fly ash (FA) were used as binders for GC. PWB, GGBFS, and FA were mixed at a ratio of 1:2:2. The proportion was determined taking into account the properties of the binder from the viewpoint of proper workability, strength, and shrinkage (behavior [Imamoto and Yoshiba]). In addition, burnt dolomite was added as an alkaline activator. The chemical composition of the binders and the alkaline activator are shown in Table 3.

Table 1. Materials used

Type of material		Specific gravity (g/cm^3)	Water absorption (%)
Pulverized waste plasterboard	(PWB)	2.31	-
Ground granulated blast furnace slag	(GGBFS)	2.86	-
Fly ash	(FA)	2.25	-
Burnt dolomite	(BD)	2.99	-
Coarse aggregate (crushed stone)		2.66	0.70
Artificial lightweight aggregate	(ALA)	1.63	26.0
Fine aggregate		2.58	2.31
Super-plasticizer	(SP)	Carboxylic acid	

Table 2. Mix proportions

Notation	W/B (%)	Unit content (kg/m^3)									
		Water (W)	Binders (B)			BD	Fine aggregate	Coarse aggregate	ALA	Air-entraining agent	SP
			PWB	GGBFS	FA						
GC50	50		72	144	144	3.6	673			2.0	2.8
GC40	40	180	90	180	180	4.5	582	972		2.7	3.5
GC30	30		120	240	240	6.0	424			4.2	6.0
GCL50	50		72	144	144	3.6	676			4.3	0.7
GCL40	40	180	90	180	180	4.5	587		591	35.6	1.4
GCL30	30		120	240	240	6.0	434			48.0	2.9

Table 3. Chemical composition of binders and alkaline activator

Notation	PWB	GGBFS	FA	BD
MgO	-	3.75	0.78	20.59
Al_2O_3	-	10.43	20.44	-
SiO_2	0.65	26.98	59.58	0.28
P_2O_5	-	-	0.88	-
SO_3	52.08	1.85	0.63	0.06
K_2O	-	0.62	2.18	0.40
CaO	46.55	53.34	4.05	78.64
TiO_2	-	1.85	2.04	-
V_2O_5	-	0.07	0.07	-
MnO	-	0.56	0.06	-
Fe_2O_3	0.54	0.37	8.88	-
SrO	0.16	0.11	0.19	-
ZrO_2	-	-	0.15	-

Unit (%)

TEST METHODS

The compressive strength, static elastic modulus, and creep coefficient were measured according to the JIS (Japanese Industrial Standards) or JSTM (Japan Testing Center for Construction Materials Standard of Testing Method) (see Table 4). The adiabatic temperature rise in GC/GCL was measured using a temperature-controlled chamber shown in photo 2. The autogenous shrinkage strain of GC/GCL was measured using an embedded gauge placed at the center of a cylindrical specimen with a diameter of 10 cm and height of 20 cm. The increase in the compressive strength, elastic modulus, creep coefficient, and adiabatic temperature of ordinary Portland cement concrete (OPC) was evaluated using a prediction equation recommended by the AIJ [Architectural Institute of Japan] or JCI (Japan Concrete Institute) (see Table 5).

Table 4. Test methods and specimen size

Item	Test method	Specimen size (mm)
Comp. strength	JIS A 1108	φ100×200
Tensile strength	JIS A 1113	
Elastic modulus	JIS A 1149	
Creep coefficient	JSTM C 7102 : 1999	

Table 5. Prediction equation for OPC

Item	Recommended by	Prediction equation
Compressive strength	AIJ	
Tensile strength		
Elastic modulus		)
Creep coefficient		,
Autogenous shrinkage	JCI	

EXPERIMENTAL RESULTS AND DISCUSSION

Compressive and Tensile strength

Table 6 shows properties of fresh concrete, such as slump, air content, and temperature. The increase in the compressive strength and tensile strength is shown in Figure 1 and 2, respectively. Initially, the compressive strength gain of GC was lower than that of OPC, but it was higher after around 14 days. GCL exhibited slightly less strength than GC.

The tensile strength of GC and GCL showed the same tendency as the compressive strength. Furthermore, the tensile strength was 10%~15% of the compressive strength. It can be observed that the relationship between the compressive strength and tensile strength of GC/GCL is similar to that of OPC.

Table 6. Properties of fresh concrete

Notation	Slump (cm)	Air content (%)	C.T (℃)
GC50	20.5	2.5	24.0
GC40	23.0	2.7	23.0
GC30	22.5	2.4	21.0
GCL50	20.0	0.3	21.5
GCL40	18.0	3.8	22.0
GCL30	16.0	2.4	22.0

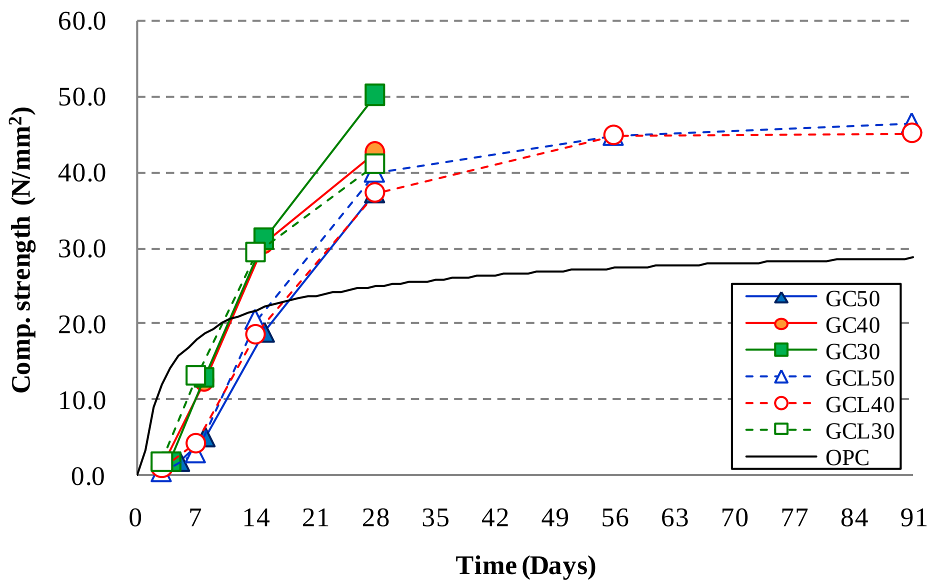

Fig. 1. Compressive strength

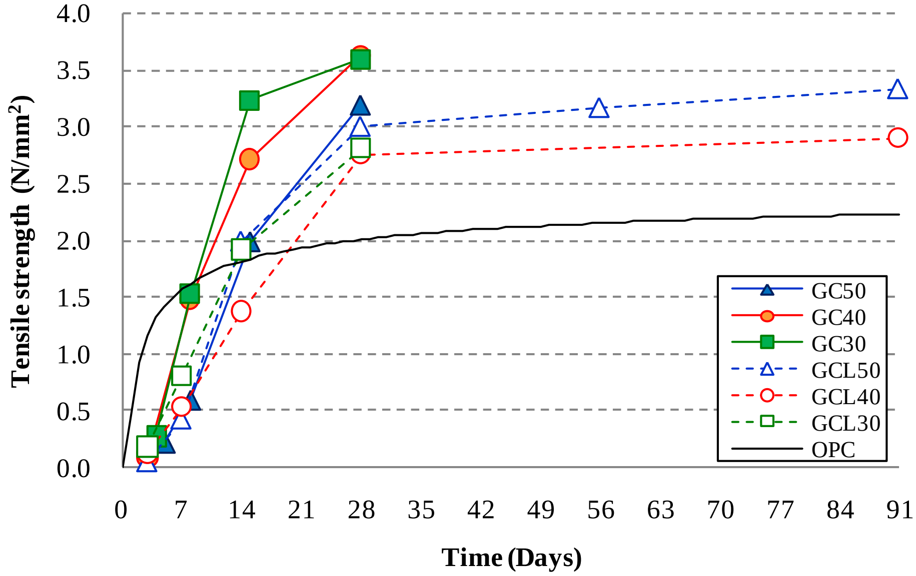

Fig. 2. Tensile strength

Elastic modulus

The increase in the elastic modulus is shown in Figure 3. Initially, the elastic modulus gain of GC was lower than that of OPC, but it was higher after around 7 days. The elastic modulus of GCL was lower than that of GC because of the low elastic modulus of the lightweight aggregate. Figure 4 shows the relationship between experimental results and the results calculated using the equation recommended by the AIJ. It can be observed that the calculated values showed a good agreement with the measured values for both OPC and GC/GCL.

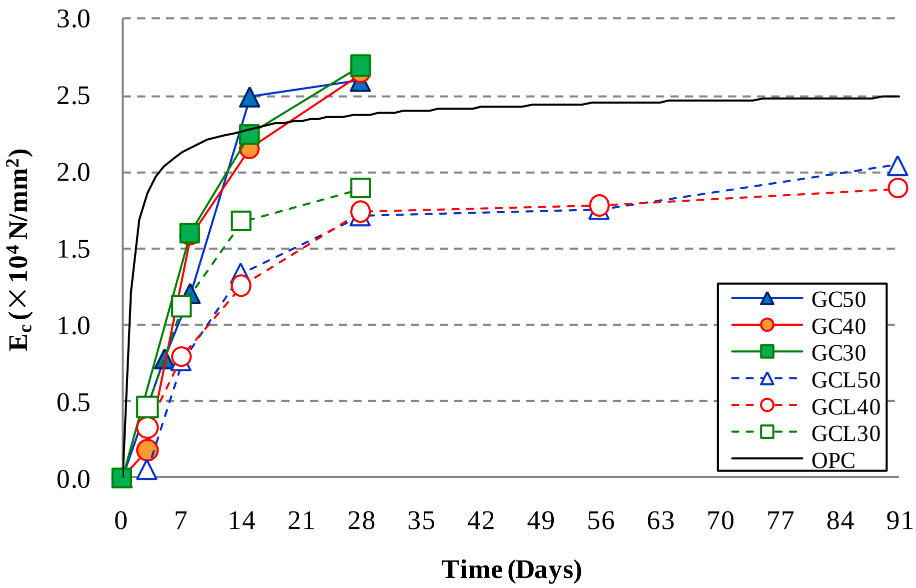

Fig. 3 Elastic modulus

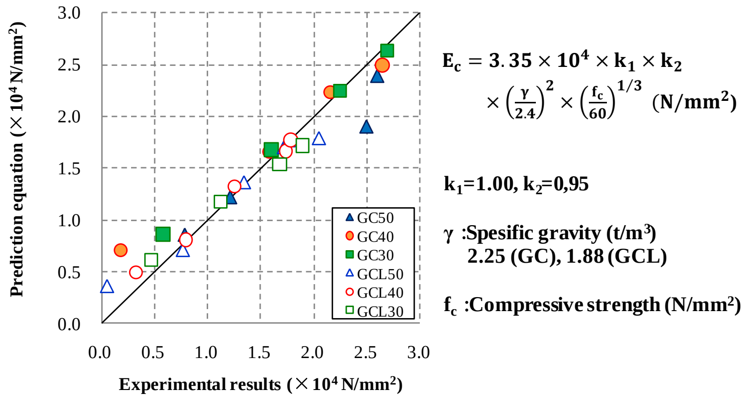

Fig. 4. Relationship between experimental results and calculated results

Creep coefficient

The creep test set-up is shown in photo 1. The creep specimens were subjected to a load stress equal to 20% of the compressive strength of the concrete at different loading ages. The creep coefficients of GC40, GCL40, and OPC are illustrated in Figure 5 and 6, respectively. The creep coefficient of GC was larger than that of OPC especially at loading age 3. Meanwhile, that of GCL was lower than that of GC. Hence, the artificial lightweight aggregate contributed to the decrease in the creep strain.

Photo 1. Creep test set-up

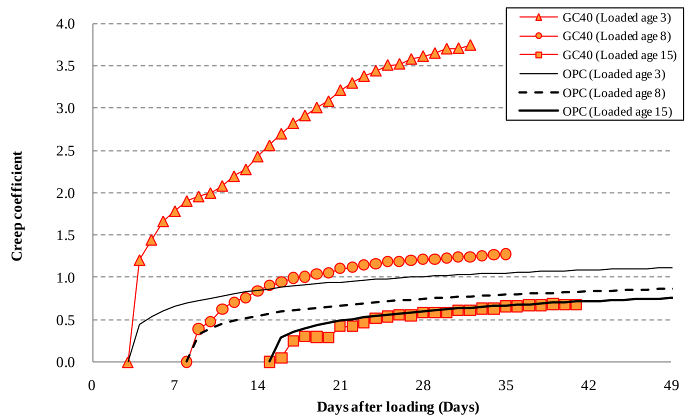

Fig. 5. Creep coefficient (GC and OPC)

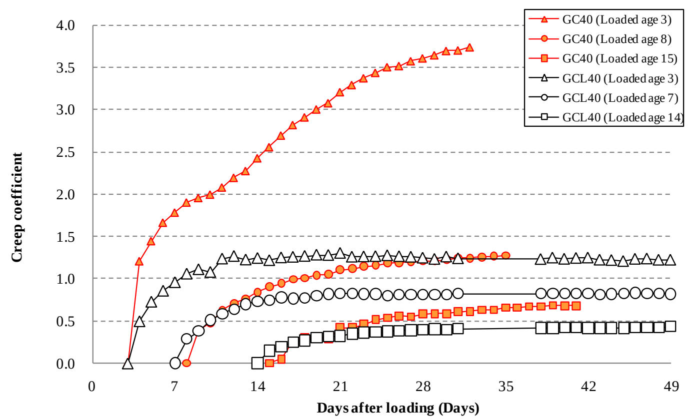

Fig. 6. Creep coefficient (GL and GCL)

Adiabatic temperature rise

Adiabatic temperature rise tests were carried out on GC/GCL (see Figure 7). The temperature rise in GCL showed the same tendency as that in GC, and the rate of temperature rise in both GCL and GC was much lower than that in OPC.

Photo 2. Temperature-controlled chamber

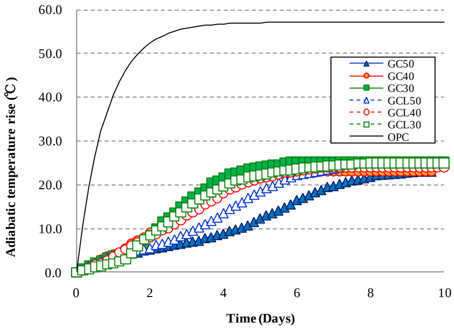

Fig. 7. Adiabatic temperature rise

Autogenous shrinkage

The method used for measuring the autogenous shrinkage strain in this experiment is discussed below. The autogenous shrinkage strain was measured using the embedded gauge placed at the center of the specimen with the size of φ100 × 200 mm. After demolding, the specimen was sealed with an aluminum foil tape to prevent moisture evaporation.

It can be observed that the autogenous shrinkage strain of GC was extremely large as compared to that of OPC. On the other hand, GCL exhibited expansion. This may be due to the adequate moisture supply from the lightweight aggregate to the cement paste matrix. Internal curing effect with moisture storage of light weight aggregate is quite significant for GC.

Drying shrinkage

The method used for measuring the drying shrinkage strain in this experiment is discussed below. The drying shrinkage strain was measured using the embedded gauge placed at the center of the specimen with the size of φ100 × 200 mm. The specimen was cured for 1 week in water at 20°C prior to drying.

It can be observed that the artificial lightweight aggregate contributed to the decrease in the drying shrinkage in general.

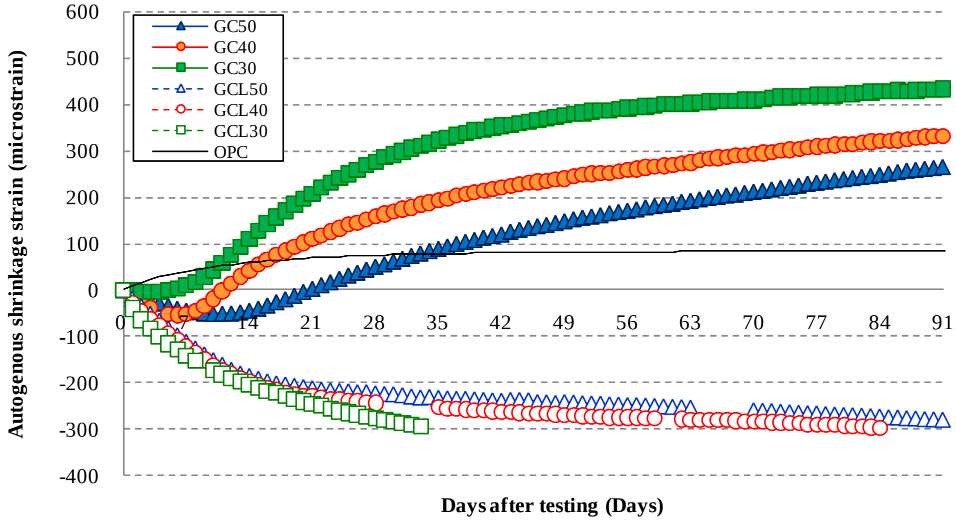

Fig. 9. Autogenous shrinkage strain

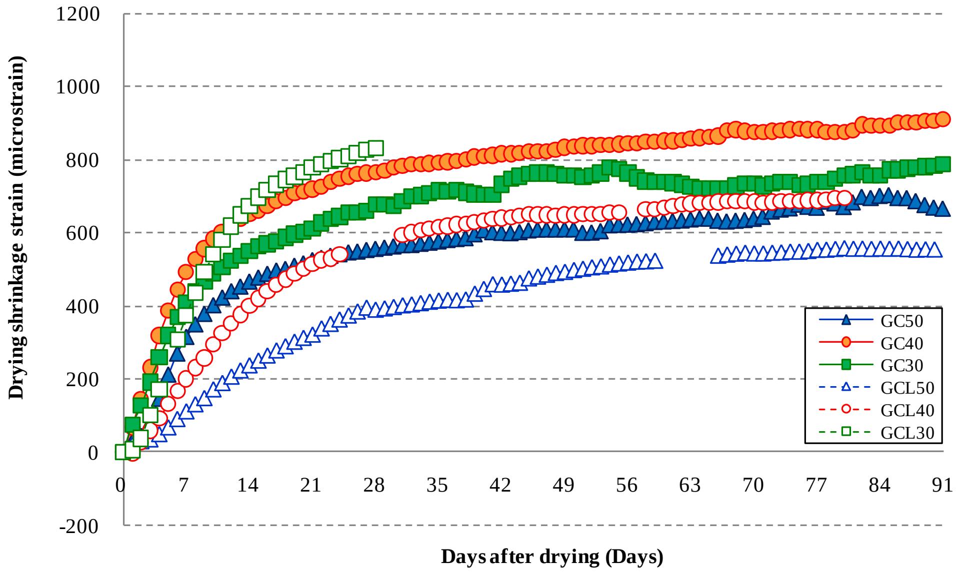

Fig. 10. Drying shrinkage strain

CONCLUSION

The following conclusions were derived from this study:

- Although the rate of strength development of GC was lower than that of OPC, the strength of GC evaluated at 28 days surpassed that of OPC.
- The elastic modulus of GC/GCL can be estimated by using the equation recommended by the AIJ.
- The autogenous shrinkage strain and the creep coefficient of GC were larger than those of OPC.

- In this study, it was found that the artificial lightweight aggregate contributed to the decrease in not only the autogenous shrinkage strain but also the creep coefficient due to its internal curing effect.

REFERENCES

Architectural Institute of Japan, (2008). “Recommendations for Practice of Thermal Cracking Control of Massive Concrete in Buildings”

K. Imamoto, M. Yoshiba and F. Iso (2007). “Environment-conscious building materials comprising pulverized plaster board, fly ash and ground granulated blast-furnace slag”, International Conference on Sustainable Construction Materials and Technologies, Proceedings of Special Sessions“ pp.157-162, Coventry, U.K., 2007.6