Resilient Structures and Sustainable Construction
Edited by Pellicer, E., Adam, J. M., Yepes, V., Singh, A., and Yazdani, S.
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ISBN: 978-0-9960437-4-8

COMPARATIVE INVESTIGATION OF STRENGTH PROPERTIES OF CONCRETE MIXED WITH VARIOUS POWDER AS ALTERNATIVE CEMENTITIOUS MATERIALS

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Mineral admixtures are often mixed in concrete as an alternative cementitious material. The use of powder materials indirectly contributes to mitigation of environmental impact caused from Portland cement production which is a major source of CO_2 emission. Furthermore, some of powder can improve properties of fresh and hardened concretes. A huge number of reports examining effects of admixture have been published in the world. However, it is not easy to compare the effect of admixture under a certain test condition. The present study aims to examining strength properties of concrete incorporating various admixtures. All admixtures tested herein were mixed in concrete as an alternative cementitious material, and the cement replacement ratios were in the range of 0.2 to 0.6. The tested powder materials are limestone powder, fly-ash, blast furnace slag powder, silica-fume, and inorganic admixture which was recently developed to increase chloride resistance. The focus of the study is to quantify the effect of these admixture on concrete strength. The paper reports compressive, split tensile and flexural strengths of these concretes, and discusses the effect of powder materials.

Keywords: Fly-ash, Blast furnace slag powder, Limestone powder, Silica-fume, Chloride resistance admixture.

1 INTRODUCTION

Global warming is a life-threatening issue for the world. Carbon dioxide (CO_2), a primary greenhouse gas, is daily emitted from Portland cement manufacturing. To mitigate the environmental impact, cement-concrete engineers and researchers should try to use of alternative cementitious materials for Portland cement (Malhotra 2006). It is well known that some kinds of byproducts such as fly-ash can be used as the alternative binders. Many researchers and engineers have been investigated on the use of such powder materials, and reported the effects of the admixture on the concrete properties (Mehta and Monteiro 2004). For example, Yoshitake *et al.* (2013) examined the properties of high volume fly ash (HVFA) concrete, and Yoshitake *et al.* (2014) reported the applicability of the HVFA concrete. Furthermore, Yoshitake *et al.* (2015) developed a recyclable fly-ash concrete pavement and examined the fundamental properties of the concrete, and Yoshitake *et al.* (2016) reported the applicability of the concrete for a rigid-pavement material.

However, most investigations dealing with the byproduct have focused on one or a few admixtures, examined the concrete properties and discussed its applicability to practical concrete structures. Hence, it is not always easy to compare the concrete properties incorporating such admixtures. The experimental study focuses on five kinds of admixtures: limestone powder (*L*); fly-ash (*F*); blast furnace slag powder (*B*); silica-fume (*S*); a commercial admixture for high-resistance chloride attack (*C*) which has been newly developed in Japan. The focuses of this investigation are to examine strength developments of concrete mixed with these powder materials and to quantify the effect of the admixture on the concrete properties. The paper shows the fundamental strength properties such as compressive, split tensile, flexural strengths, and discusses the effect of these powder materials.

2 METHODOLOGY

2.1 Materials

Materials used in the experimental investigation are summarized in Table 1. Ordinary Portland cement defined in a Japanese Industrial Standard (JIS R 5210) was used. Fine and coarse aggregates employed herein are general aggregate in western Japan. The commercial admixture for high-resistance chloride attack is a kind of inorganic pozzolanic powder material. Detailed information of the admixture cannot be released because of a commercial contract with the manufacturer.

Table 1. Materials.

Material	Type	Property
Water	Tap-water (W)	Density 1.00 g/cm^3
Cement	Ordinary Portland cement (OPC)	Density 3.16 g/cm^3, Blaine fineness 3280 cm^2/g
Powder materials	Limestone powder (L)	Density 2.71 g/cm^3, Blaine fineness 3640 cm^2/g
	Fly-ash (F)	Class II (JIS A 6201), Density 2.22 g/cm^3, Blaine fineness 3530 cm^2/g
	Blast furnace slag powder (B)	Density 2.90 g/cm^3, Blaine fineness 4840 cm^2/g
	Silica-fume (S)	Density 2.21 g/cm^3
	Chloride resistance admixture (C)	Density 2.36 g/cm^3, BET fineness 13.3 m^2/g
Fine aggregate	Sea sand (S1)	Density 2.60 g/cm^3, FM 2.91, Size 5-0 mm
	Crashed stone sand (S2)	Density 2.60 g/cm^3, FM 2.90, Size 5-0 mm
Coarse aggregate	Crashed stone (G1)	Density 2.71 g/cm^3, Size 20-15 mm
	Crashed stone (G2)	Density 2.70 g/cm^3, Size 15-5 mm
Chemical admixture	Air entraining and water reducing agent (WRA)	Lignin sulfonate, oxy-carboxylate and poly-carboxylic acid-based compound
	Air entraining and high-range water-reducing agent (HRWRA)	Poly-carboxylic acids-based compound
	Antifoaming agent (AFA)	Nonionic surfactant

2.2 Mixture Proportions

Table 2 gives the mixture proportions of concrete. To compare the effect of powder materials, concrete tested in the study were made with cement-replacement ratios of 0.2, 0.4 and 0.6. It should be noted that some kinds of concrete mixture were not made because of inappropriate fresh properties. The water-cementitious material ratio (*w/cm*) was designed as 0.55 to simulate a general-purpose concrete mixture in ready-mixed concrete of Japan. The mixed volume ratios of aggregate were S1:S2 = 0.4:0.6, and G1:G2 = 0.5:0.5, respectively.

Table 2. Mixture proportions.

Mix. ID	Unit weight (kg/m^3)												
	W	OPC	***L***	***F***	***B***	***S***	***C***	S1	S2	G1	G2	Chem. ad.	
Control	162	295	-	-	-	-	-	618	265	488	486	1.18[a]	-
L20	162	236	59	-	-	-	-	612	262	488	486	1.18[a]	-
L40	162	177	118	-	-	-	-	607	260	488	486	1.18[a]	-
L60	162	118	177	-	-	-	-	601	258	488	486	1.18[a]	-
F20	162	236	-	59	-	-	-	604	259	488	486	1.18[a]	-
F40	162	177	-	118	-	-	-	589	253	488	486	1.18[a]	-
F60	162	118	-	177	-	-	-	575	246	488	486	1.18[a]	-
B20	162	236	-	-	59	-	-	615	264	488	486	1.48[a]	-
B40	162	177	-	-	118	-	-	612	262	488	486	1.33[a]	-
B60	162	118	-	-	177	-	-	609	261	488	486	1.48[a]	-
S20	162	236	-	-	-	59	-	603	259	488	486	4.43[a]	37[c]
S40	162	177	-	-	-	118	-	589	252	488	486	5.31[b]	81[c]
C20	162	236	-	-	-	-	59	607	260	488	486	4.13[a]	-
C40	162	177	-	-	-	-	118	595	255	488	486	5.16[b]	-

a: WRA; b: HRWRA; c: AFA (g/m^3)

2.3 Test Methods

All strength tests in the study were conducted by referring to Japanese Industrial Standards. The tests were conducted at the ages of 1, 3, 7, 28 and 91 days. Table 3 summarizes the compression, splitting tension and bending tests.

Table 3. Test methods, specimens, and test ages.

Tests	Test method	Specimens	Test ages (days)
Compressive strength	JIS A 1108, 2006	Cylindrical specimens (100 mm diameter x 200 mm long)	1, 3, 7, 28 and 91
Compressive Young's modulus	JIS A 1149, 2010	Cylindrical specimens (100 mm diameter x 200 mm long)	28
Splitting tensile strength	JIS A 1113, 2006	Cylindrical specimens (100 mm diameter x 200 mm long)	3, 7, 28 and 91
Flexural strength	JIS A 1106, 2006	Prismatic specimens (100 mm width, 100 mm height and 400 mm long)	3, 7, 28 and 91

3 RESULTS AND DISCUSSION

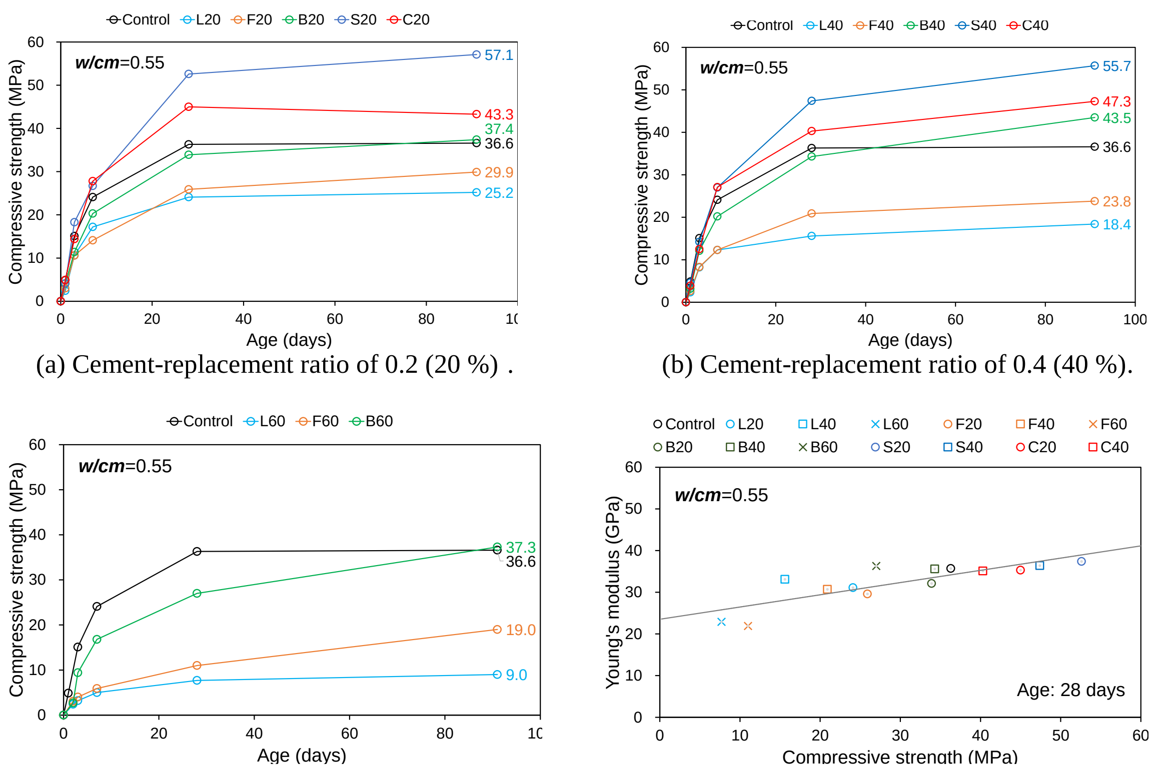
3.1 Compressive Strength and Young's Modulus

Figure 1(a), (b), and (c) present compressive strengths of concrete made with the cement-replacement ratios of 0.2, 0.4, and 0.6, respectively. For the comparison, the compressive strength development of control concrete is also shown in these graphs. In addition, relationship between Young's moduli and compressive strength at 28 days is presented in Figure 1(d).

The concrete incorporating limestone powder (***L***20, ***L***40 and ***L***60) indicated the lowest strength in each cement-replacement ratio. The results confirm that the limestone powder hardly reacts under cement hydration while other admixtures indicate pozzolanic reaction and/or latent hydraulicity. It may be of interest that the strengths of concrete made with blast furnace slag powder (B20 and B40) are almost similar to the strength of control concrete though the concrete (B60) indicated lower strength than the control. The observation confirms the utility of powder, which is generally used in blast-furnace slag cement as an alternative material of Portland cement. Fly ash concrete in the study indicated lower strength development than the control and the blast furnace slag powder concretes. Fly ash is well known as a pozzolanic powder that contributes strength development at long-later ages. The strength contribution of fly ash was hardly observed in the test range of the present study.

Silica-fume is often used in high strength concrete because the powder is a pozzolanic material and contributes micro-filler effect in pore structure. In this experimental investigation, the silica-fume concrete indicated the highest strength in each test case (cement-replacement ratio of 0.2 and 0.4). The chloride resistance admixture is a kind of pozzolanic powder material with a BET specific surface area of 13 m^2/g, although the detailed chemical compositions cannot be released here because of a contract with the manufacturer. It is noteworthy that the concrete made with the admixture indicated higher strength than the control concrete, as well as the silica-fume concrete.

Figure 1(d) shows that Young's modulus increases slightly in accordance with the increase of compressive strength. However, remarkable influences of the powder materials on the modulus of concrete were not observed in the test result.



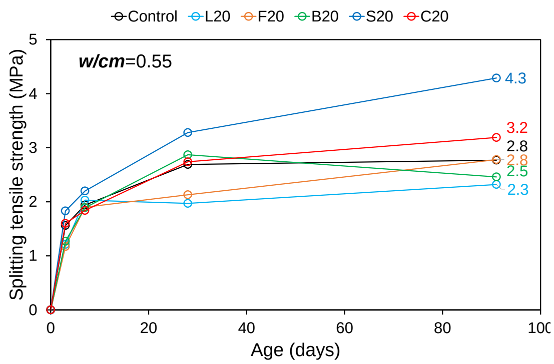
(a) Cement-replacement ratio of 0.2 (20 %) .

(b) Cement-replacement ratio of 0.4 (40 %).

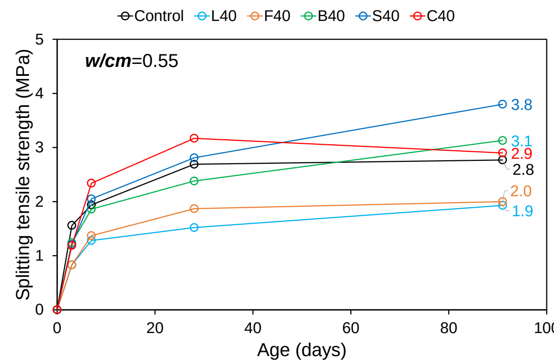
(c) Cement-replacement ratio of 0.6 (60 %).

(d) Young's modulus – comp. strength.

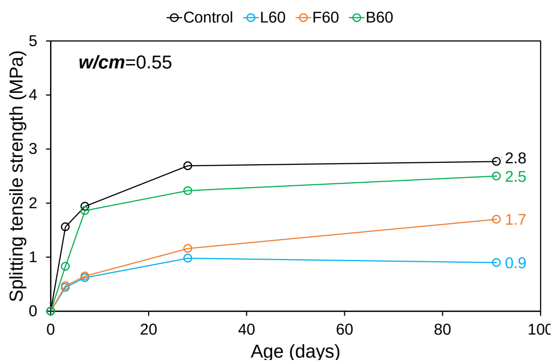
Figure 1. Compressive strengths and Young's moduli.



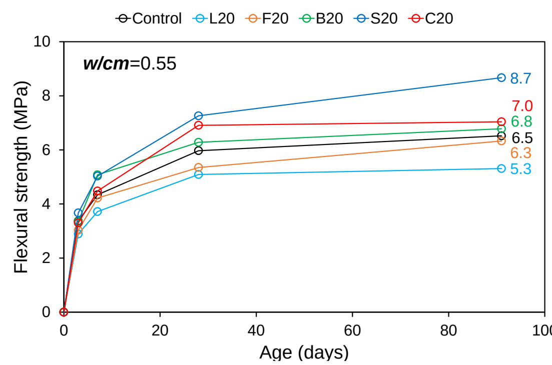
(a) Splitting tensile strength (*CRR = 20 %).



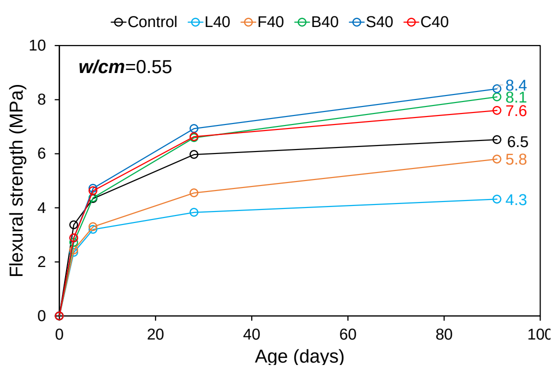
(b) Splitting tensile strength (*CRR = 40 %).



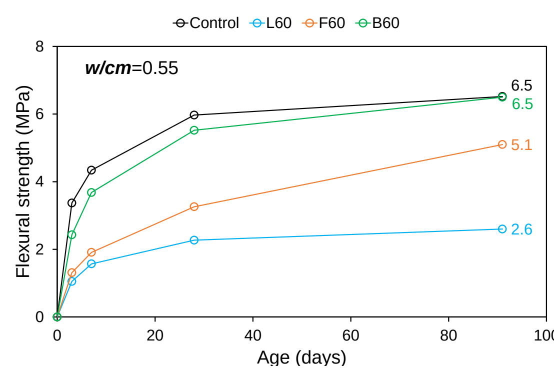
(c) Splitting tensile strength (*CRR = 60 %).



(d) Flexural strength (*CRR = 20 %).



(e) Flexural strength (*CRR = 40 %).



(f) Flexural strength (*CRR = 60 %).

Figure 2. Splitting tensile and flexural strengths (*CRR = cement-replacement ratio).

3.2 Splitting Tensile and Flexural Strengths

Figure 2(a), (b), and (c) show the splitting tensile strengths of concrete incorporating each admixture which mixed by the cement-replacement ratios of 0.2, 0.4, and 0.6, respectively. As well as the compressive strength test, the concrete mixed with limestone powder indicated the lowest tensile strength. It must be caused from the slower pozzolanic reaction as mentioned earlier that the splitting tensile strength of fly ash concrete also indicated relatively lower strength than control concrete. The test results show that significant differences in the concretes incorporating the blast-furnace slag powder, the chloride resistance admixture and the silica-fume were not observed except for the concrete (***S***20).

Figure 2(d), (e), and (f) present the test results of flexural strength of each concrete as well as the slitting tensile strength test. The results confirm that the relatively low strengths were also observed in limestone powder and fly ash concrete. As well, the concrete replaced with silica-fume of 20 percent (***S***20) indicated the highest strength in all bending test. It may be due to the micro filler effect of the finest powder material in addition to the pozzolanic reaction.

To examine the effect of the chloride resistance admixture, the study investigated the strength properties of concrete made with artificial powder. Note that the use of the powder as an alternative cementitious material hardly decreased tensile and flexural strengths. Observations imply that the powder material can contribute to reduction of cement content (a source of greenhouse gas) and improvement of durability such as high resistance to chloride attacks.

4 CONCLUSIONS

The study reported the strength properties of concrete incorporating cementitious alternative materials: limestone powder; fly-ash; blast furnace slag powder; silica-fume; admixture of high-resistance chloride attack. The experimental study revealed the effects of the admixture on strength properties. The conclusions of the study are as follows:

- The limestone powder contributes the micro-filler effect, nevertheless the concrete mixed with the powder indicated the lowest strength. The comparative result implies that the limestone powder hardly reacts under cement hydration while other admixtures indicate pozzolanic reaction and/or latent hydraulicity.
- The concrete made with chloride resistance admixture or silica-fume indicated higher strength than the control concrete, confirming that these materials can be used as an effective alternative binder in addition to the improvement of pore structures of concrete.
- Test results confirmed that Young's moduli are generally related to the compressive strength and is affected by the powder material used as an alternative cementitious material.
- Splitting tensile and flexural strengths indicated similar tendency to the compressive strength, however, the effects of powder material were not significant compared to the differences in compressive strength.

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