論　文

[1202] A Study on Frost Resistance and Strength Properties of High Strength Concrete Using Andesite and Limestone

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ABSTRACT

Frost resistance and strength properties of high strength concrete are experimentally evaluated to find out the factors, which affect these two important properties of concrete.

Twelve factors, namely type of coarse aggregate, surface condition of coarse and fine aggregates, mixing and casting procedures, removal age , type of mold, type of mixer and the testing machine are assumed to be paramount importance. An experimental design analysis was carried out to evaluate the affecting factors simultaneously.

Despite the low water-cement ratio, deterioration of the specimens during freeze-thaw cycles were observed. The analyses variance indicate that, the type of coarse aggregate, mixing and casting procedures strongly affect both the frost resistance and the strength properties.

Using andesite as the coarse aggregate produced a concrete with significantly higher compressive strength and frost resistance than that of with limestone.

The results of thermal coefficient measurement of the coarse aggregate declare that, the low thermal coefficint of the limestone compared with andesite, may be responsible for low frost resistance of the limestone concretes.

Keywords: high strength concrete; frost resistance; compressive strength; modulus of elasticity; experimental design method; andesite; limestone; **thermal coefficient**

1. INTRODUCTION

The papers published so far, contain little or contradictory information on the frost resistance of high strength concrete. For instance, some authors(1) obtained excellent results for resistance to freeze-thaw of all high strength concrete, having water-cement ratio of 0.25 to 0.35 , whether air entrained or non air entrained agent. They attributed this , to the greatly reduced freezable water contents and also the increased tensile strength of high strength concrete. However, there are many results (2), which indicates poor or low frost resistance of high strength concretes.

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On the other hand, some published literatures about elastic modulus of high strength concrete state that, high compressive strength values may not necessarily lead to high elastic modulus values. They attribute this, more to the effect of the coarse aggregates than to the water cement ratio.

In this paper, influence of the twelve factors on the frost resistance and strength properties of the high strength concrete is examined. The water-cement ratios are 0.28 and 0.35.

2.EXPERIMENTAL DESIGN

In this study, basically 16 units of experiments were conducted for twelve factors each at two levels, which is described by L16. The water-cement ratio and testing age were incorporated as secondary factors in freeze thaw and compressive strength tests.

The levels used for each factor are given in table 1. The complete test series are also shown in the table 2.

As it is shown in table 1, two levels of mixing method are as follows:
In level 1 all of the materials were mixed at the same time.
The mixing method in level 2 are given at the bottom of table 1.

Table 1. The Factors and the Levels

Factors		Factor code	Level of Factors 1	2
Mixer Capacity		A	55(lit)	75
Coarse Agg.		B	Limestone	Andesite
Surface Condition of:	Coarse Agg.	C	Saturated	Dry
	Fine Agg.	D	Saturated	Dry
Mixer Type (Axes Direction)		E	Vertical	Horizontal
Mixing Time		F	2(min.)	4
Mixing Method (Mixing Material)		G	At the same time	In the Order*
Mixing Temp.		H	10℃	30℃
Type of Mold in: (Compressive Test)		I	Disposable	Ordinary
Compact Method		J	JIS A 1132	Vibrator Table
Removal Age		K	1(day)	2
Testing Machine		L	100 Tons	200

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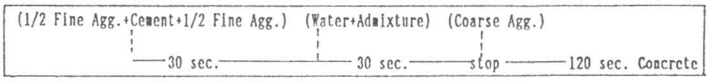

The specimens were cured in sealed condition at the cast temperatures until removal age and then were cured at 20℃ for the specified period. Air content, slump and flow were measured immediately after mixing.

The freeze-thaw tests were carried out according to ASTM C666-A.The testing age for compressive strength was 1, 2, 4 and 13 weeks.

Table 2. L16 Factorial Design

Test Series	G	B	H	F	G F	C	J	A	L	I	F E	K	D	G E	E
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2
3	1	1	1	2	2	2	2	1	1	1	1	2	2	2	2
4	1	1	1	2	2	2	2	2	2	2	2	1	1	1	1
5	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2
6	1	2	2	1	1	2	2	2	2	1	1	2	2	1	1
7	1	2	2	2	2	1	1	1	1	2	2	2	2	1	1
8	1	2	2	2	2	1	1	2	2	1	1	1	1	2	2
9	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
10	2	1	2	1	2	1	2	2	1	2	1	2	1	2	1
11	2	1	2	2	1	2	1	1	2	1	2	2	1	2	1
12	2	1	2	2	1	2	1	2	1	2	1	1	2	1	2
13	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1
14	2	2	1	1	2	2	1	2	1	1	2	2	1	1	2
15	2	2	1	2	1	1	2	1	2	2	1	2	1	1	2
16	2	2	1	2	1	1	2	2	1	1	2	1	2	2	1

3.MATERIALS AND MIXING PROPORTIONS

Ordinary portland cement, river sand and two types crushed stone as the coarse aggregates (limestone and andesite) were used. The superplasticizer and AE entrained agent are used. The slump is equal to 20±2 cm.

The physical properties of the aggregates are given in table 3. The mix proportions of the concrete are given in table 4.

Table 3. Properties of the Aggregate

Agg-regates	Specific Gravity. Saturated Surface Dry	Specific Gravity. Oven Dried	Absorption Water (%)
Fine Agg.	2.68	2.63	2.04
Andesite	2.65	2.57	3.00
Limestone	2.69	2.67	0.93

Table 4. The Mix Proportions of the Concrete

W/C (%)	S/A (%)	Cement (Kg/m3)	Water (Kg/m3)	Coarse Agg. (Kg/m3)	Fine Agg. (Kg/m3)	Ad. (Cement%)	A.E. (Cement%)
35	43.5	486(154)	170	966(359)	737(277)	1.7	0.004
35	43.5	486(154)	170	955(359)	737(277)	1.7	0.004
28	41.0	607(192)	170	939(353)	652(245)	2.2	0.005
28	41.0	607(192)	170	950(353)	652(245)	2.2	0.005

The number in Parantesis are the Volume of the Materials(l/m3)

4. TEST RESULTS

4.1 Freezing and Thawing

For both the water-cement ratios, the durability factors and air(%) of all the 16 series are summarized in figures 1 and 2. It is to be noted that, for the 0.28 water-cement ratio , deterioration of the specimens started at the 70 cycles freeze-thaw. As it is shown in figure 1, the durability factors of about half of these series are below 60. For 0.35 water-cement ratio, except two series, the durability factors are under 60. As it is shown, the air contents of the specimens are not in an unique relationship with durability factors. In the other words, durability factors did not follow the air content of the concrete. For instance, in 0.28 water cement ratio, the concrete with a low air content(2.55), has durability factor equal to 100 (series 5). whereas, in 0.35 water cement ratio, the specimens with high air content (6.25%), produced the concrete with durability factor equal to 17.

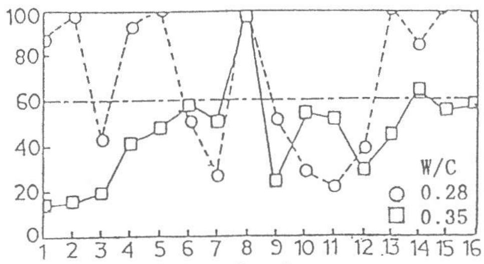

Fig.1 Durability Factors of the Concretes

Figure 3 shows the factors which are significant at 1% and 5%.

At 1% significant value, The type of coarse aggregates and W/C ratio as in figures 3(a and b), are important. The former is influenced 2 times than of the latter. Andesite, with high absorption water value produced more daurable concrete.compare with limestone.

The factors which are significant at 5% are given in figures 3(c,d,e,f).

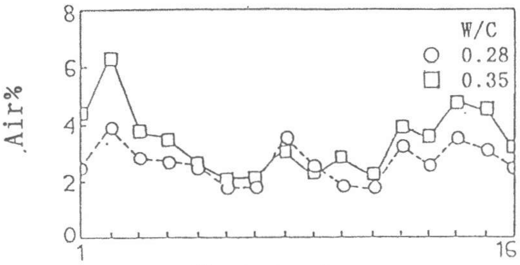

Fig.2 The Air Content of the Concrete

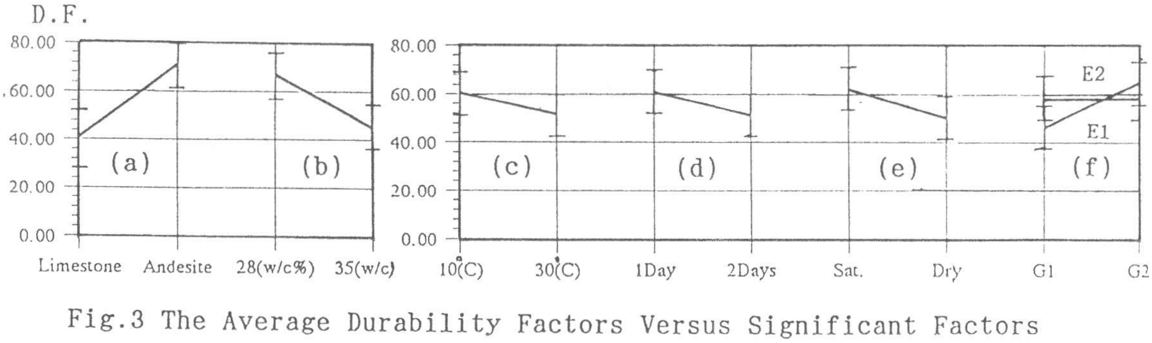

Fig.3 The Average Durability Factors Versus Significant Factors

4-2. Compressive Strength

For both the water-cement ratios, the compressive strength results of sixteen test series were analyzed to evaluate the significant factors. Type of the testing machine, as an parameter, was used to limit its influence on the test results. In this regard, two types of testing machines were considered to clarify effect of this factor on the results.

The analyses variances of compressive strength at 4 weeks are given in table 5. As it is shown, the water-cement ratio was also accounted as a secondary factor. The significant factors at 1% and 5% are marked by star and are given in figure 4.

At the 1% significant value, type of coarse aggregate, mixing time, type of testing machine, compact method and W/C ratio are important, as in figures 4(a,b,c,d,e).

At 5% significant value, the type of mixer, casting temperature, removal age are significant.

Considering W/C ratio as a secondary factor, at 1% value, the interaction of mixing method and mixing time is significant, fig. 4(f). Whereas, at 5%, surface condition of coarse aggregates, mixing time, mixing method, re-moval age and the interaction of mixer type and mixing time are important.

Table 5. Analysis Variances of Compressive Strength at 4 weeks

Factor Code	Freedom Degree (df)	Mean Sum Squares (ms)	Variance Ratio (F)	Factor Effect (%)
A	1			
B	1	11074	55.1**	10.8
B	1			
C	1			
D	1			
E	1	21812	10.85**	2.1
F	1	28468	14.15**	2.7
G	1			
H	1	21656	10.76*	2.06
I	1			
J	1	31628	15.72**	3
K	1	18780	9.33*	1.77
L	1	71008	35.30**	6.9
G*F	1			
F*E	1			
G*E	1			
e1				
e'1	7	2012		
total	15	325976		
W/C(M)	1	627156	1372**	61.42
A*M	1			
B*M	1			
C*M	1	2580	7.13*	0.1
D*M	1			
E*M	1			
F*M	1	4236	11.7*	0.3
G*M	1	2720	7.52*	0.2
H*M	1			
I*M	1			
J*M	1			
K*M	1	2060	5.7*	0.1
L*M	1			
G*F*M	1	5808	16.1**	0.5
F*E*M	1	2492	6.88*	0.18
G*E*M	1			
e2				
e'2	7	362		
total	31	977780		
e3	64	660.19		4.1
TOTAL	95	1020030		96.23

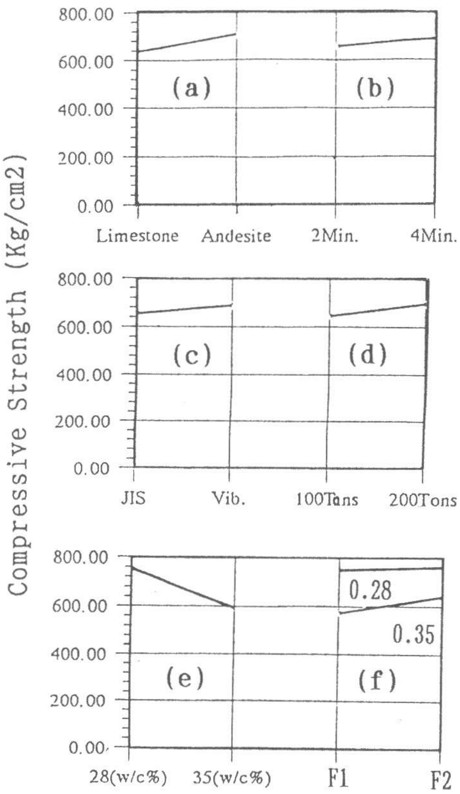

Fig.4 The Average Compressive Strength versus Significant Factors

4-3 Modulus of Elasticity

The results of analyses variance for secant modulii of elasticity at 4 weeks are given in figure 5. As it is shown, the factors which influenced the results at 1%, are:

Type of coarse aggregate, water-cement ratio, mixing temperature, compact method and testing machine.

It is interesting to note that the type of coarse aggregates influenced the results more strongly than water-cement ratio fig. 5(a,b). Limestone aggregates produced concrete with high secant modulus than the andesite one. The high mixing temperature(30C), the compact by vibrator (J2) and the 100 tons testing machine influenced the results more than the other level of these factors, figures 5(c, d, e).

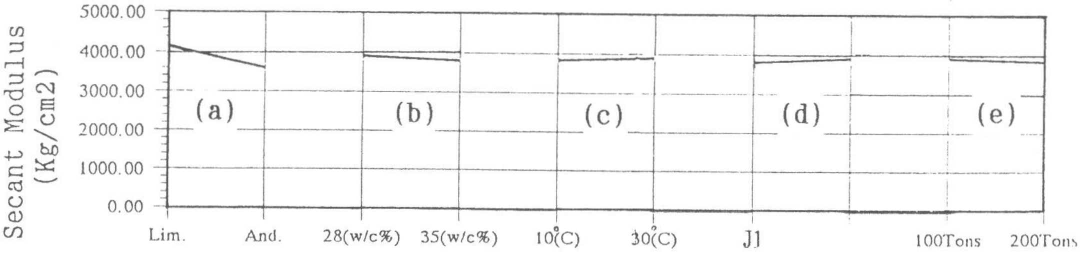

Fig.5 The Average Secant Modulus at 4 weeks versus Significant Factors

5.DISCUSSION

5-1 A Summary of Analyses Variances

The purpose of this study was, to investigate about the main factors which influence frost resistance and strength properties of high strength concrete. This study declares that, the idea of low W/C ratio being the only factor which produces a durable concrete is not valid. In this regard, analyses of variances stat ed that, the effect of coarse aggregate on frost resistance and modulus of elasticity is 2 and 4 times more than water cement ratio, as is given in table 6.

On the other hand, water cement ratio plays a vivid rule in compressive strength results.

At present, building codes use expressions relating modulus of elasticity to the compressive strength , which in turn is related to the water cement ratio. Example of the relationship are as follows

Table 6. Affecting % of Coarse Agg. and W/C on Properties of the Concrete

Concrete Property	Coarse Agg. (%)	W/C
Frost Resistance	25.2	13.5
Comp.Strength	10.7	61.4
Modulus Elasticity	59.4	16.8

ACI commitee 363: $E'_c = 3.32\ (f'_c)^{0.5} + 6.9$

CEB(1990): $E'_c = 10\ (f'_{cyl} + 8)^{0.33}$

in which (f'_c) is the compressive strength of cyliders(M.Pa) and E'_c is modulus of elasticity (G.Pa)

Therefore, a formula which account the effect of coarse aggregate is necessary.

5-2 THERMAL COEFFICIENT MEASUREMENT

As an effort to find out the causes of frost damage of the specimens, thermal coefficient value of the aggregate was investigated.

Three electric strain gauges, sensisitive to 1 micromilimeter were installed on the surface of the aggregates in three dimensions. The specimens were passed through a slow temperature cycles +20℃ to -20 ℃ in 24 hours period. Figure 6 shows the thermal strain of the aggregates during cycles of freeze-thaw. Thermal coefficient of the aggregates were calculated as folows:

$$\alpha = \frac{\varepsilon}{\Delta t}$$

in which α is thermal coefficient and ε is strain of aggregates due to differences of temperatures (Δt)during freeze-thaw cycle.
The measured thermal coefficient are given in table 7. As it is shown, the coefficient of andesite is about 1.5 times larger than the limestone

Table 7. Thermal Coefficient of the Aggregates

Aggregate	Thermal Coefficient		
	Axis 1	Axis 2	Axis 3
		milionths	
Andesite	5.68	5.70	6.52
Limestone	3.75	3.80	4.53

However, the low thermal coefficient of limestone may be one reason for existance of high thermal stresses during freeze-thaw cycles, which may lead to disrupt the concrete

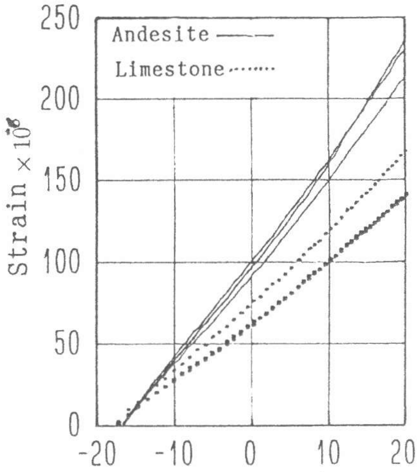

Fig.6 Thermal Strain of the Aggregates versus Temperature

6.CONCLUSION

Influences of twelve factors on the concrete specimens with 0.28 and 0.35 (W/C) were considered, the follwing conclusion is drawn:

1. Frost resistance and strength properties of the concretes are influenced by the Two significant factors (W/C ratio and type of coarse aggregate), the latter is two times more effective than the former.
2. Andesite produced more durable concretes than the limestone.
3. The low thermal coefficient of limestone are considered to be responsible for the frost damage of limestone concrete.
4. W/C ratio influenced the compressive strength more strongly than the aggregate type.
5. The elastic modulus of the concrete is strongly influenced by the type of coarse aggregate than by the water cement ratio.

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