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論文 The Required Compressive Strength and Prehardening Time to Prevent Damage to High Flowing Concrete from Frost Damage at Early Ages

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ABSTRACT: This investigation was undertaken to develop data on the early frost resistance of high flowing concrete made either with various type of mineral fine powders or viscosity agents. From the results of this investigation it was found that the test cylinders cast from air entrained concrete (ie., air >3.5%) which cured up to 23 ° D.D prior to freezing, performed with satisfactory resistance to early freezing and thawing cycles. However the 28 days strength ratio of all AE specimens were above 100%. This study recommends early continuous protection until AE high flowing concrete has attained compressive strength of 70 to 80 kgf/cm².

KEYWORDS: compressive strength, early freezing, frost damage, high flowing concrete, loss of strength, mineral fine powder, prehardening time, strength ratio, viscosity agent.

1. INTRODUCTION

Freezing of concrete during setting period and initial stage of hardening may cause serious damage; therefore this problem is of great economic importance. It is believed that when fresh ordinary concrete is exposed to sufficiently low temperature the free water in concrete is cooled below its freezing point and transforms to the ice crystals on the surface of aggregate particles and in the cement paste. The growing ice crystals extract water from the mortar. Thus mortar is forced to give space to crystals and in this way aggregate particles separate from surrounding mortar. The formation of ice crystals due to freezing at early ages, prevents the development of bond between the coarse aggregate and cementitious matrix which counts for most of the decrease in compressive strength and damages to the concrete specimens[1]. The above phenomena have been studied in numerous laboratory and field tests for ordinary concrete[2,3]. but there is not enough information on this subject relating to high flowing concrete mixtures. To obtain data on this subject, the cylinders of different types of high flowing concrete mixes at various time intervals up to 40 hours after casting, were tested in accordance with ASTM test for resistance of concrete to rapid freezing and thawing (C666) procedure B.

2. EXPERIMENTAL PROGRAMS

2.1 MATERIALS AND MIXING PROPORTIONS

The cementitious materials and mineral fine powders used in this investigation included-

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normal Portland cement (JIS R5210) produced at a plant in Hokkaido, with a specific gravity of 3.16, and surface area of 3320 cm²/g, type B of blast furnace slag cement as specified in (JIS R5211) with specific gravity of 3.05 and surface area of 3770 cm²/g, the highly fine graded granulated furnace slag of blain size of 5950 cm²/g and specific gravity of 2.9, silica fume and three different type of viscosity agents which are commercially available in market named as Acryle, Cellulose and Polysaccharide. These are abbreviated to AC, CE and PO respectively. The coarse aggregate (C.A) used was crushed stone with specific gravity of 2.65 and nominal maximum size of 20 mm. The fine aggregate (S.A) was local natural sand with specific gravity of 2.75 and fineness modulus of 2.69. Sand to aggregate ratio(S/A) for all mixes except silica fume was 0.52. The admixture consisted of high rang air entraining water reducing agent of polycarbon based superplasticizers (SP) and air entraining agents (AEA) and non air entraining admixture as (NAE).

Table 1. Mix proportions and some properties of the fresh concrete.

2.2 MIX PROPORTIONING

From trial mixes, two series of concrete mixtures were selected. These series are defined by type of cementitious material, and mineral fine powder as series I and type of viscosity agent as series II. Each series consisted of two or more mixes with the air content less than 3.5% specified as non-AE and more than 3.5% as AE concrete. Table 1 shows mix proportions and some properties of the fresh concrete mixes.

2.3 MIXING, CURING, AND TESTING PROCEDURES

Concrete mixing was carried out in a 100 liter capacity vertical pan mixer. The procedure for mixing concrete is shown in Figure 1. The mixing time was fixed to 6 minutes in order to obtain the desired value of consistency and air content. The properties of fresh concrete; including temperature, slump flow, and air content, were measured fifteen minutes after mixing.

The concrete test specimen used for evaluation of resistance to cycles of freezing and thawing was 10 φ × 20 cm cylinders. These cylinders were filled in two layers and hammered after each layer, then they were immediately cured in constant room temperature of 10°C for 16, 22, 28, and 40 hours prior to exposing them to freezing and thawing. The maturity function $M = \Delta t \sum (T + 10)$ was applied in order to obtain the maturity of specimens at 16, 22, 28, and 40 hours after casting, which are 13.33, 18.33, 23.33, and 33.33 °D.D respectively. M is maturity, Δt is the curing time interval in day, and T is temperature of the concrete mixes at the time t.

Conc rete Type	Mix No	Target air (%)	W/C (%)	S/A (%)	W	C	kg/m ³					Air (%)	Slump flow (mm)
							Additive	S.A	C.A	SP (%)	AE (%)		
OPC+ Slag6000	3-sL	<3.5	35	52	160	206	251	935	831	1.2	1.5*	2.6	650
	3-SL	>3.5	35	52	160	206	251	919	819	1.2	0.8	5.8	648
OPC+ Slag-Cement	3-sB	<3.5	35	52	160	457	—	937	833	1.5	1.0*	2.4	675
	3-SB	>3.5	35	52	160	457	—	937	833	1.5	0.4#	3.7	600
	3-SB	>3.5	35	52	160	457	—	923	821	1.5	0.08	4.3	685
OPC+ Acryle	3-aC	<3.5	35	52	180	514	3.0	891	792	1.5	0.6	1.9	635
	3-aC	<3.5	35	52	180	514	3.0	891	792	1.5	0.25	2.5	625
	3-AC	>3.5	35	52	180	514	3.0	876	779	1.5	0.1#	4.9	675
	3-AC	>3.5	35	52	180	514	3.0	876	779	1.5	0.0	4.5	635
	4-aC	<3.5	42	52	180	429	4.5	929	826	1.8	0.4*	2.7	665
	4-aC	<3.5	42	52	180	429	4.5	929	826	1.8	0.0#	3.5	665
OPC+ Cellulose	4-cE	<3.5	42	52	170	405	0.20	954	848	1.5	0.15#	3.3	655
	4-CE	>3.5	42	52	170	405	0.20	940	836	1.5	0.2	4.4	645
OPC+ Polysaccharde	4-pO	<3.5	42	52	170	405	0.25	954	848	1.3	0.0#	2.7	635
	4-PO	>3.5	42	52	170	405	0.25	940	835	1.3	0.05	5.6	640
OPC+ Silica - Fume	3-sF	<3.5	35	48	165	424	22.4	849	886	2.5	0.0#	2.5	667
	3-SF	>3.5	35	48	165	424	22.4	836	873	2.5	0.05	4.5	663

SL=Slag 6000

SF=Silica fume

SB=Slag cement (type B)

3=W/C=35%, 4=W/C=42%

S/A=Sand aggregate ratio

small letter =Air content less than 3.5%

capital letter=Air Content more than 3.5%

CE= Cellulose(Viscosity agent)

SP = AE high range water reducing agent of poly carbon based superplasticizer (SP8SX3) for Cellulose concrete and (SP8SX2) for other type of concrete mixe

* = AE 404 # = AE 775S

AC =Acryle(viscosity agent)

PO =Tateru(Viscosity agent)

At each of the specified curing ages, six cylinders were removed from the curing room to the test lab. Three of them were demolded and were capped by gypsum and prepared for compression testing, and the rest were weighed and placed into the freezing and thawing container. The container provided continuous freezing in air and thawing in water in accordance with ASTM 666, "procedure B". A freeze thaw cycle of -20 to 10°C taking approximately six hours was employed until 4 cycles had been obtained. After 4 cycles, test specimens were removed from the freeze and thaw container to determine weight, observe its appearances, and take photograph of their conditions. The undamaged specimens were sealed by a thin plastic foil followed by two layers of plastic film and left in a curing room of 20°C constant temperature and 100% relative humidity until the time of compressive strength (28 days). This type of curing is much closer to the normal field curing than water curing. The standard cylinders were made on each test for comparison, these were removed 16 and 40 hours after casting from 10°C curing room and sealed by plastic film and then placed in the curing room for 28 days.

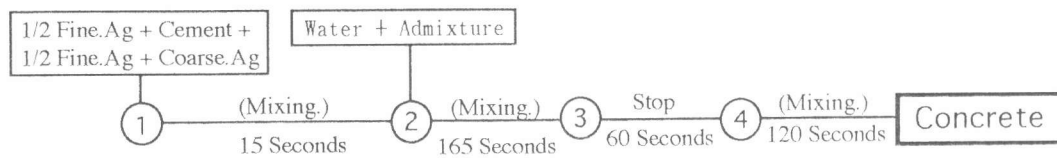


Fig. 1 Mixing procedure of the concrete

3. DISCUSSION OF RESULTS

3.1 STRENGTH DEVELOPMENT AND MATURITY CONCEPT.

The results of compressive test cylinders at early ages, based on the maturity concept is shown from figures 2(a) to 2(f). Figures 2(a) and 2(b) show the strength development of concrete made with different types of mineral fine powders. As shown silica fume concrete, designated as sF, developed significant strength even at 28 hours after casting. The blast furnace slag denoted as sL appeared to be less active than slag cement and silica fume concrete. The reason is that the reaction of slag consumed part of the calcium hydroxide formed during earlier age of hydration. The strength development of viscosity type concrete, is shown in Figures 2 (c), (d), (e), and (f). The importance of the effect of W/C ratio on the strength gain is evidenced from considering figures 2 (c) and (d). It can be seen that the higher the W/C ratio, is the less the rate of strength development would be. Fig.2 (e) shows that the gain of strength of all viscosity agents concrete are nearly the same. However the acryle concrete with water to cement ratio=42% shows lesser gain of strength, in comparison with others.

3.2 RESULTS OF COMPRESSION TESTS.

The results of the compression tests at 28 days, are presented as a ratio of the compressive strength of the specimens, which have experienced freezing and thawing cycles at the early age to the compressive strength of the corresponding standard cured concrete specimens. This ratio in percent, is called "strength ratio" and is indicated by S_r . The judgment of specimens conditions after freezing thawing action, was made in terms of this parameter. In other words a concrete specimen that has experienced freezing and thawing action, depending on its condition, can be categorized as; failed specimen $0 \leq S_r \leq 50\%$, damaged specimen $50 < S_r < 80$, Partial safe specimen $80 < S_r < 90$, and it is safe if $S_r \geq 90\%$.

The early age compressive strength, strength ratio, and air content relationships of both series of the concrete mixes are shown in Figure 3. From this figure, it is apparent that most of the non AE specimens failed to resist 4 cycles of freezing and thawing at early ages.

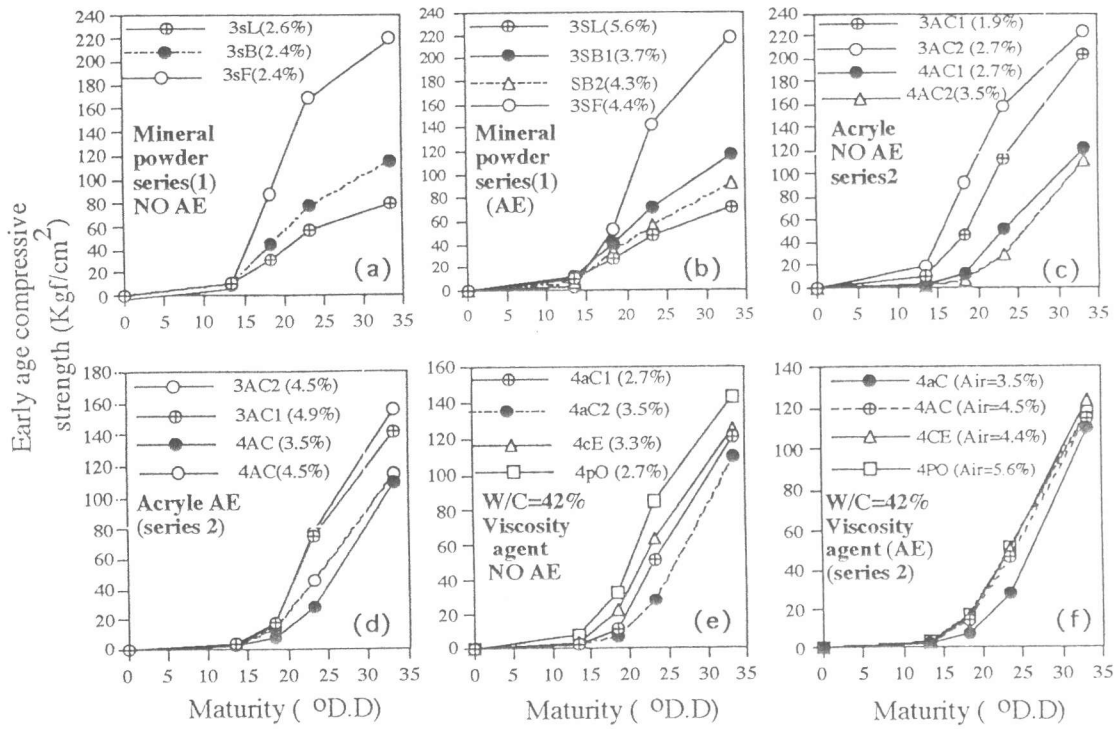


Fig. 2 The early strength development and maturity relationship. a & b Mineral =fine powder, c = Acryle (w/c=35%), d = Acryle (w/c=42%) and e & f= (Acryle, Cellulose and Polysaccharide) viscosity agent concrete.

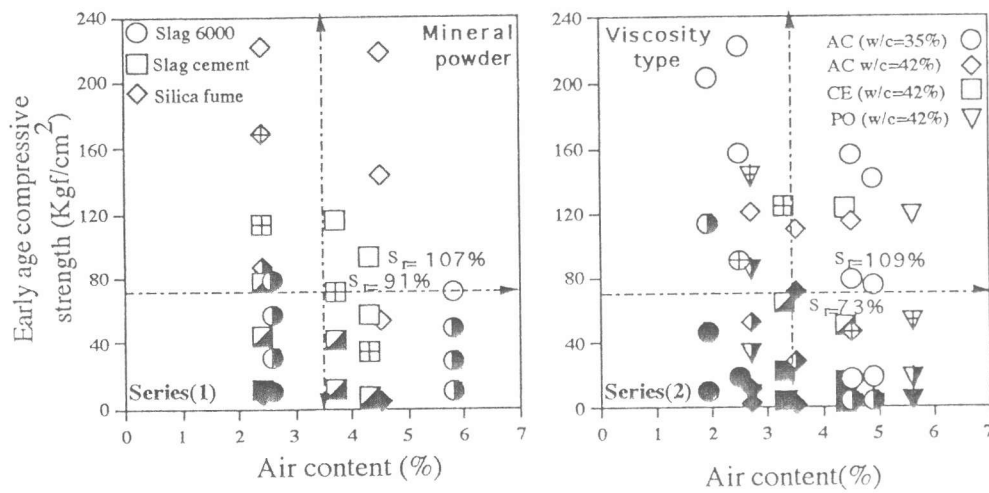


Fig. 3 Early compressive strength and air content, relationship of different types of concrete mixes, in term of strength ratio which is categorized as:

- $R_c = 0 - 50\%$ as failed specimen
- ▣ $R_c = 50 - 80\%$ damaged
- ▤ $R_c = 80 - 90\%$ as partially safe
- $R_c > 90\%$ safe specimen

It is well known that hardened air entrained in concrete offers great resistance to repeated freezing and thawing. The result of freezing and thawing tests in this investigation show that the most of the AE concrete specimens at very early ages, either failed or were badly damaged under freezing and thawing action. This is quiet evidenced from considering Figure 3. The reason is that the beneficial influence of air bubbles is not effective until the concrete has hardened sufficiently. In fresh concrete, ice crystals form independently of the existence of air bubbles, and the decrease in compressive strength is about the same for AE and no AE concrete. However it was found that the required upper safe limit of compressive strength of AE concrete to resist the freeze thaw cycles at early ages was in the range of 70-80 Kgf/cm².

3.3 THE REQUIRED PRE- HARDENING TIME AND COMPRESSIVE STRENGTH

To define the minimum period of protection and early compressive strength, in order to prevent the concrete mixes from frost damage, the loss of compressive strength of concrete specimens which have been frozen relative to the standard concrete was computed and the results are illustrated in Figure 4. Based on the freezing and thawing results and visual observation of the specimens, it was found that 10% loss of strength (i.e., $S_I=90\%$) is a lower limit for accepting a concrete mix as frost resistance. By considering Figure 4 it is seen that for example the slag cement concrete designated as 3SB(4.3%), the loss of strength at pre hardening time of 16 hours is 45% (unsafe specimen) while it reduces to -2% after 28 hours (safe specimen). The intersection of the horizontal line passing through 10% loss of strength with each curve in Fig 4a gives the required pre hardening time. knowing the required pre hardening time, and using Figure 4.b the required early compressive strength can be found. However for this particula case the required time and compressive strength are 25 hours and 52 Kgf /cm² respectively.

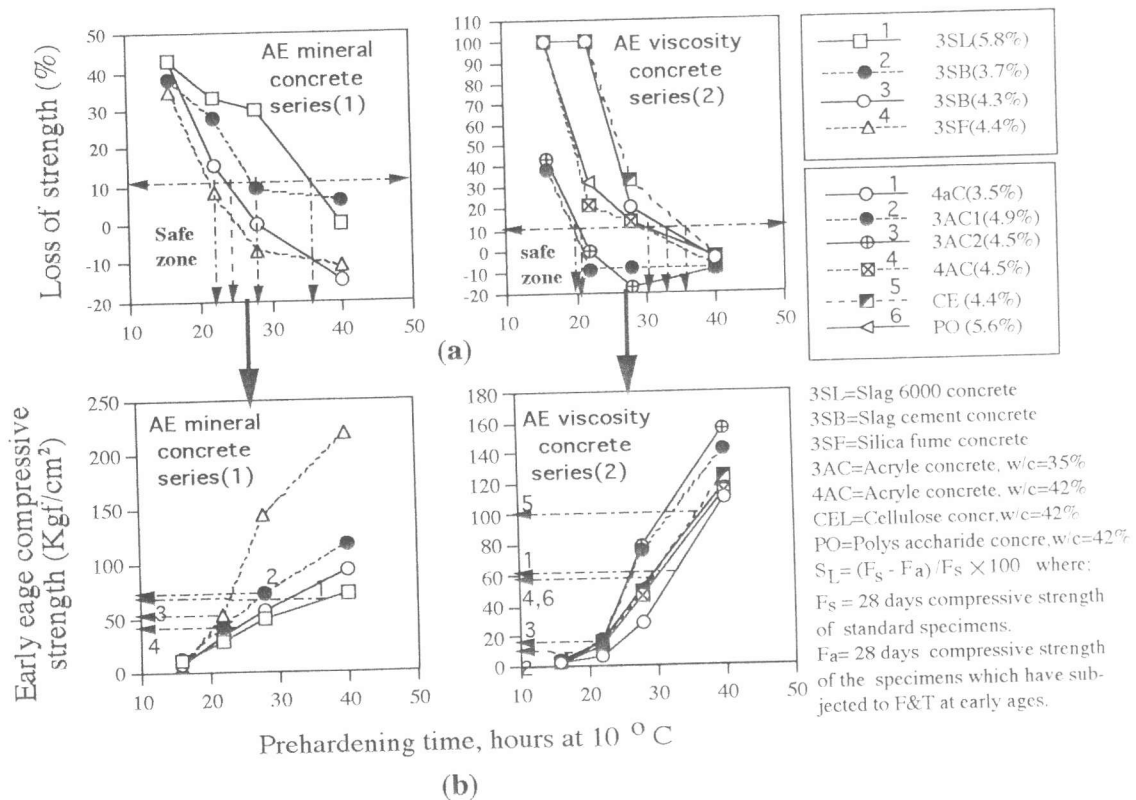


Fig. 4 Relations between the required prehardening time, loss of strength, and early age compressive strength to protect the concrete specimens from freezing at early ages.

For the aim of comparison, the required prehardening time to develop compressive strength of 50 and 80 Kgf/cm² are shown in figure 5. The former value is specified in " JAS5 as a safe limit to prevent ordinary concrete specimens from frost damage and later value is out line of the present study for high flowing concrete mixes.

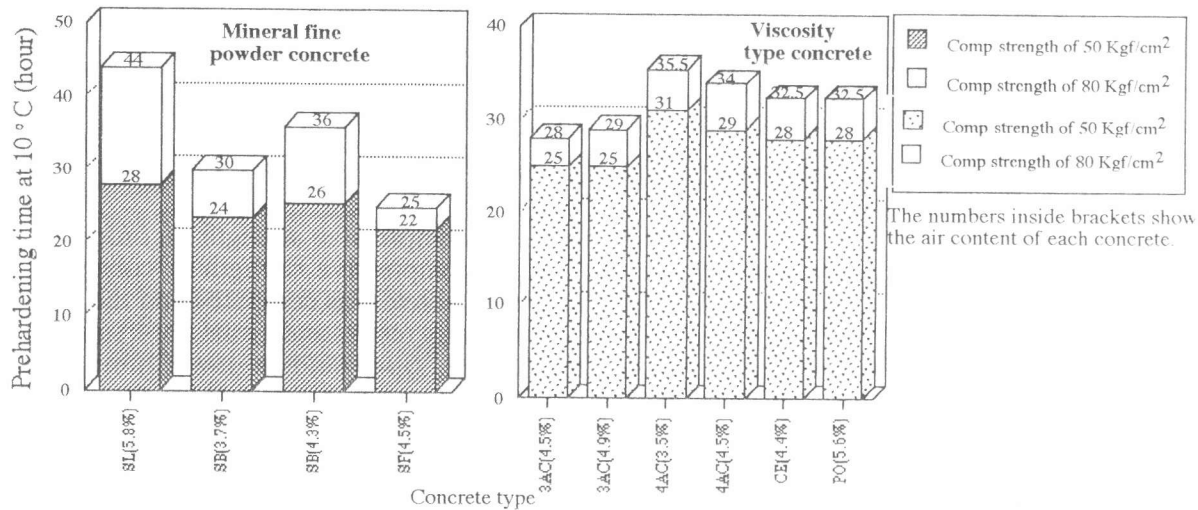


Fig.5 The required prehardening time for developing compressive strength of 50 and 80 Kgf/cm² in variouce types of AE high flowing concrete.

4. CONCLUSIONS

From results of this investigation, it is possible to draw the following conclusions.

1- Regardless of the concrete type, almost all the test specimens cast from non air entrained concrete (air<3.5%), except a few cases, failed to resist freeze thaw cycles at early ages. The test cylinders cast from air entrained concrete (air>3.5%) which cured up to 23° D.D, prior to freezing and thawing, were performed with satisfactory resistance to the early freeze and thaw cycles. However; the strength ratio of all AE concrete specimens which cured more than 23° D. D were above 100%.

2- This study recommends continuous protection until AE and non-AE concrete specimens; depending on the type of concrete, have attained compressive strength of 70-80 and 120-150 kgf/cm² respectively.

3- It was observed that the concrete specimens which have experienced freeze and thaw cycles can not recover strength, equivalent to the standard specimens concrete.

4 -Air-entraining admixtures did not show any influences on the frost damage to young concret specimens.

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