Effect of Air-Entrained Agent on Fresh and Hardened Properties of Cement Mortar

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Abstract

Freezing and thawing action is the main cause of the deterioration of the reinforced concrete structures. It decreases its durability if appropriate precaution is not taken into account. In order to minimize the effect of freezing and thawing action, generally 4~7% of air content by volume of concrete is introduced into the concrete. Air content in the concrete is considered as the combination of the entrapped air and entrained air. Entrapped air is minimized as less as possible during the compaction process of concrete and instead, the microscopic air cells are entrained into the concrete by using air entrained agent during the mixing. This paper is focused on the content of highly effective air-entrained agent (AE 303A), on the fresh and hardened cement mortar. The air content of mortar was increased from 2.7% to 10.5% while using 0.01% of AE 303A by weight of cement. The density of fresh mortar was decreased from 2.261 g/cm^3 to 2.078 g/cm^3 and that of hardened mortar was from 2.238 g/cm^3 to 2.039 g/cm^3. With similar trend of decreasing densities, seven days compressive strength was decreased from 43.12 MPa to 27.37 MPa. However, no significant difference was observed on the workability of mortar, measured in table flow value while increasing the AE 303A content.

Keywords : Air content, air entrained agent, compressive strength, density, freezing and thawing action, workability

I. INTRODUCTION

A concrete is “durable” if in its environmentit it has provided the desired service life, without excessive cost for maintenance and repair due to degradation or deterioration. Durability is not a property of concrete. Concrete that would be immune to the effects of freezing and thawing is of no higher “quality” than one that has no ability to resist freezing and thawing if is to be used where it can never freeze in a critically water saturated condition [1].

Air-entrained concrete contains billions of microscopic air cells per cubic foot. These air pockets relieve internal pressure on the concrete by providing tiny chambers for water to expand into when it freezes. Air-entrained concrete is produced using air-entraining Portland cement, or by the introduction of air-entraining agents under careful engineering supervision as the concrete is mixed on the job. The amount of entrained air is usually 4 to 7% of the volume of the concrete, but may be varied as required by special conditions [2]. Usually causes the porosity to increase thereby, decreasing the strength of concrete. However, there are other important benefits of entrained air in both freshly mixed and hardened concretes. Besides the increase in freeze-thaw and scaling resistances, air-entrained concrete is more workable than non-entrained concrete. The use of air-entraining agents also reduces bleeding and segregation of fresh concrete [3].

K. H. Khyat evaluated the self-consolidated concrete (SCC) mixtures for slump flow consistency, restricted deformability and surface settlement, strength development, elastic modulus, temperature rise, shrinkage, permeability, and frost durability. Examples of the use of such concrete for repair of a densely reinforced beam in a parking structure and a moderately reinforced beam-wall element with restricted access in a powerhouse were also discussed. Test results clearly indicated the feasibility of proportioning air-entrained SCC of high stability and resistance to blockage. Optimized mixtures exhibited adequate engineering properties and durability. The field studies demonstrated the effectiveness of such high-performance concrete to repair damaged sections presenting difficulties for placement and consolidation [4].

The freeze-thaw durability of plain concrete is poor,

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but it can be improved greatly when air-entraining agent is mixed into concrete. It demonstrates that ordinary strength concrete can also have high freeze-thaw durability [5].

W. Sun et al. determined the loss of dynamic elastic modulus and the flexural strength of specimens subjected to freeze-thaw cycles. Their experimental results showed that the damage process is accelerated and the extent of damage increased under the simultaneous action of load and freeze-thaw cycles. The lower the grade of concrete, the greater the damage is. At a higher stress ratio, concretes suffer more serious damage. The addition of steel fiber or air entrainment or the combination of the two to concrete can improve its ability to resist damage[6].

Use of air entrainment can result in a multitude of beneficial effects. However, too much can seriously undermine strength without improving durability. Very little weatherability is gained by air content over 4%, but 6% air does offer better control of segregation and water gain. Mixes with air contents of upto 12%still exhibit the same resistance to weathering as those in the 4% to 6% air range. The breaking point appears to occur at slightly over 12% at which durability begins to decrease markedly [7].

Air entrainment can reduce the ingredients of concrete without any effect on the workability of the concrete mix, which means that more economical concrete mix can be achieved by using air entrainment agent. However, decreasing concrete compressive strength while increasing air entrainment should be considered. The reduction of cement due to increase of air entrainment in the concrete mix results in a lower heat of hydration in mass concrete (dams as example). The decrease in temperature due to the hydration process results in reduction of cracking and any undesirable internal stresses [8].

The presence of entrained air causes a slight reduction in water requirement, flexural strength, and the dynamic modulus of elasticity of concrete, and increases the durability from 5 to 50 times, depending upon the quantity of entrained air and the coarse aggregate [9].

Giridhar et al. concluded that slump values were increased when percentage of admixture improved. Compaction factor values also improved when admixture increased. Compressive strength of air entrained concrete decreased when admixture percentage increased. Split tensile strength also decreased when percentage of admixture increased [10].

Most of the previous research works have shown the result that the use of air entrained agent increases workability and reduces segregation and bleeding of fresh concrete [11, 12, 13, 14].

However, in this paper, the investigated experimental results on properties of fresh and hardened mortar when taking the parameter of AE 303A with very small content in varying percentage has been described .

II. OBJECTIVE

The main aim of this research work was to investigate the effect of very less varying percentage of AE 303A on fresh and hardened properties of mortar. Its specific objectives are:

(1) To study the effect of varying percentage of AE 303Aon air content, density and, flow behavior of fresh mortar.

(2) To study the effect of varying percentage of AE 303A on density and compressive strength of hardened mortar.

(3) To study the decreasing and increasing trend of each property while increasing the percentage of AE 303A.

III. EXPERIMENTAL PROCEDURE

The mortar of Dam-B type concrete was chosen for this series of experiments. Specific gravities of water and chemical admixtures were considered as 1.0. Specific gravities of cement and sand were 3.16 and 2.67 respectively. The mix proportion of basic mortar is given in Table I. The content of AE admixture (No. 70) was 0.25% by weight of cement in each mortar mix. It was used to enhance the workability of mortar. The content of AE303A was chosen as varying parameter with 0%, 0.0025%, 0.0050%, 0.0075%, and 0.010% by weight of cement. These chemical admixtures were used in concrete as part of water. The mix proportion of basic mortar is the standard with consideration of 7% air content with the use of 0.25% of No. 70 and 0.0050 % of 303A, generally used in Dam-B type concrete.

TABLE I.

MIX PROPORTION OF BASIC MORTAR

Concrete Mix Type	Mix Proportion Condition		Unit Content (Kg/m^3)				
	W/C (%)	S/C	W	C	S	Chemical Admixtures	
						No. 70	303A
Dam- B	48.7	2.47	262	538	1329	1.345	Varying

W: Water, C: Cement, S: Sand, No. 70: AE admixture, 303A: High efficient air entrained agent

The mixing experiment was carried out in 10 litres capacity mortar mixer. The volume of each batch of mortar was 10 litres. The water content to be batched for 10 litres mortar was adjusted with moisture content of sand as well as the weight of chemical admixtures to be used.

The batched chemical admixtures were pre-mixed with water by stirring with a spoon in the bucket. Cement and sand were introduced into the mixer in sandwich, half of sand in bottom and top with whole cement in between sand. Dry mixing of cement and sand was carried out for 30 seconds at low speed. Mixer was stopped and finer particles accumulated on inner surface and bottom was drawn to mix with the mortar. The water was then added and further mixed for one minute. Again, the mixer was stopped and checked if any unmixed particles remained on inner surface and bottom. Finally, the mixing was done with high speed for further one minute. The mixing procedure was same for each batch of mixing.

All required tests and specimens making were done with the standard procedure as prescribed by Japanese Industrial Standard (JIS).The ambient temperature of mortar was noted prior to any tests. Table flow value was taken as the average of maximum and minimum diameter of the flowing mortar in surface of table after tamping 10 times. Density of fresh mortar was measured with the sample after the completion of air content test in air meter. 5 numbers of φ5mm × 10 mm cylinders were prepared for 7 days compressive strength test. The density of hardened mortar was determined using these cylinders 7 days prior to the compressive strength tests.

IV. TEST RESULTS

The test results of fresh mortar are summarized in Table II.

Both ambient and mortar temperature test results showed that all experiments and tests were carried out almost in the same environment. The air content of mortar,without AE 303Awas 2.7%; however, it was increased up to 10.5 % while using 0.0100% by weight of cement. The trend of air content was increasing while increasing the content of AE 303A. Fresh density of mortar without AE 303A was obtained as 2.261 g/cm^3, but it decreased to 2.078 with 0.0100% of the air entrained agent. The trend of fresh density was decreasing while increasing the AE 303A content. Interestingly, there was no significant change in table flow value with the increase of AE 303A content in mortar.

TABLE II.

SUMMARISED RESULT OF FRESH MORTAR PROPERTIES

AE 303A Content (%× C)	Temperature (°C) Ambient	Temperature (°C) Mortar	Air Content (%)	Table Flow value (mm)	Fresh Density (g/cm^3)
0.0000	13	17	2.7	241	2.261
0.0025	14	17	4.8	246	2.203
0.0050	16	18	8.5	244	2.140
0.0075	16	18	9.0	246	2.098
0.0100	14	16	10.5	244	2.078

The test results of 7 days hardened densities and compressive strengths are summarized in Table III. Both the data of 7 days average density and compressive strength are the average value from the tests of five numbers of φ5mm×10mm cylinders. The 7 days average density and compressive strengths were obtained 2.238 g/cm^3 and 43.12 MPa respectively. While using 0.0100% of AE 303A, both the density and compressive strength were obtained as 2.039 g/cm^3 and 27.37 MPa. The trend of both densities and compressive strengths were found in decreasing order while increasing the content of AE 303A.

TABLE III.

SUMMARIZED RESULT OF DENSITIES AND COMPRESSIVE STRENGTHS OF MORTAR IN 7 DAYS

AE 303A Content (%×C)	Hardened Average Density (g/cm^3)	Variation Coefficient (%)	Average Compressive Strength (MPa)	Variation Coefficient (%)
0.0000	2.238	0.22	43.12	2.16
0.0025	2.156	0.51	38.30	3.51
0.0050	2.107	0.18	31.58	3.02
0.0075	2.071	0.30	29.64	0.74
0.0100	2.039	0.19	27.37	1.36

V. ANALYSIS AND DISCUSSION

Fig. 1 shows the relation between table flow value and the air entrained agent content. Despite increasing the content, no significant difference was noticed on the workability of mortar. The flow values were almost constant with range of 241 mm to 246 mm and with no trend of increasing or decreasing order.

The reason behind it was that 0.25% of AE No. 70 admixture by weight of cement was used to maintain the required workability of mortar in all mixes. In comparison, the content of AE 303A was extremely less

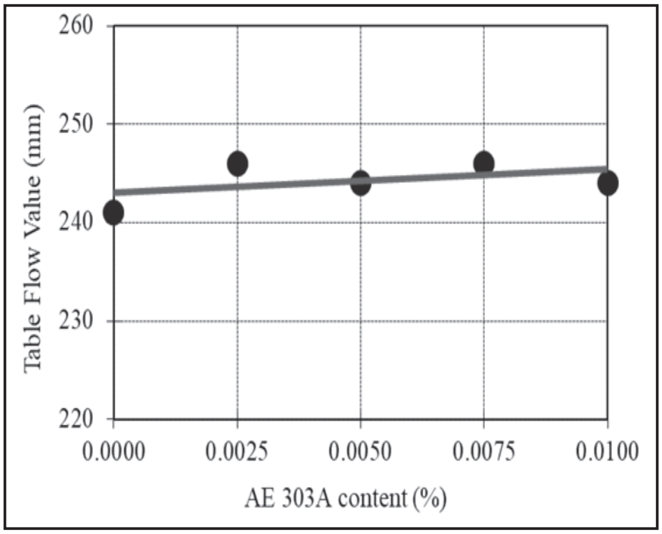

Fig. 1. Relation Between Air Entrained Agent and Table Flow Value

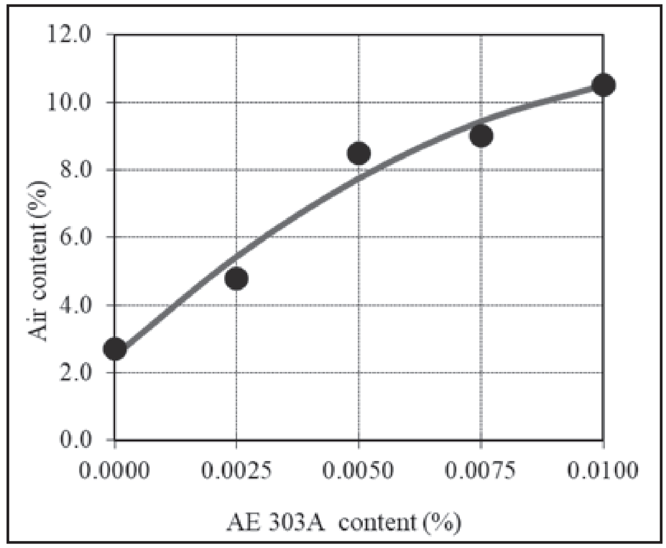

Fig. 2. Relationship Between Air Content and Air Entrained Agent Content

which could generate numerous micro bubbles of air inside the mortar but could not make the water more lubricant to increase the workability. Even increasing the content upto 0.0100%, the capacity of AE agent was significantly increased to produce more micro air bubbles in mortar, but still did not have the capacity to make water more lubricant to enhance the workability. It shows that the use of highly efficient air entrained agent does not have capacity to enhance the workability.

Fig. 2 shows the relationship between air content and air entrained agent content. When increasing the AE agent, the air content also increases with the power curve. The relation between the air content and AE agent has been formulated as given in equation 1.

$$A_C = C_1 A_e^2 + C_2 A_e + C_3 \qquad (1)$$

Here, C_1 and C_2 are constants depending upon the effectiveness of highly efficient air entrained agent. C_3 is the constant depending upon other any normal AE admixtures and the entrapped air. In this experimental work with use of AE 303A, values of C_1, C_2 and C_3 were obtained as 50,000, 1,300, and 2.5 respectively. The solid line in the graph of calculated values with developed formula and the markers are test results of air content.

The relationship between the 7 days hardened density of mortar and air entrained agent content is given in Fig. 3.The decreasing trend of the hardened density of mortar shows the exponential decay curve with the content of air entrained agent.

Equation 2 is the tentative empirical formula to relate the hardened density of mortar with the content of AE agent. In the equation, γ_h is the density of hardened mortar, and C4 is the constant depending upon the properties of ingredients, mix proportion, and compaction condition.

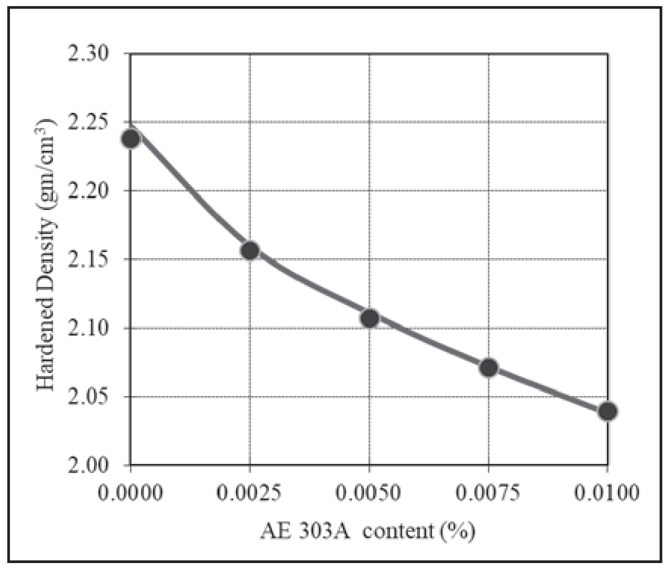

Fig. 3. Relation Between the 7 days Hardened Density of Mortar and Air Entrained Agent Content

$$\gamma_h = \frac{1}{(A_e^{0.67} + C_4)} \qquad (2)$$

In the figure, markers represent the average value of test results, and the solid line represents the calculated values using equation 2. The value of C4 was 0.445 in this analysis.

Fig. 4 shows the relationship between 7 days compressive strength of mortar and air entrained agent content.

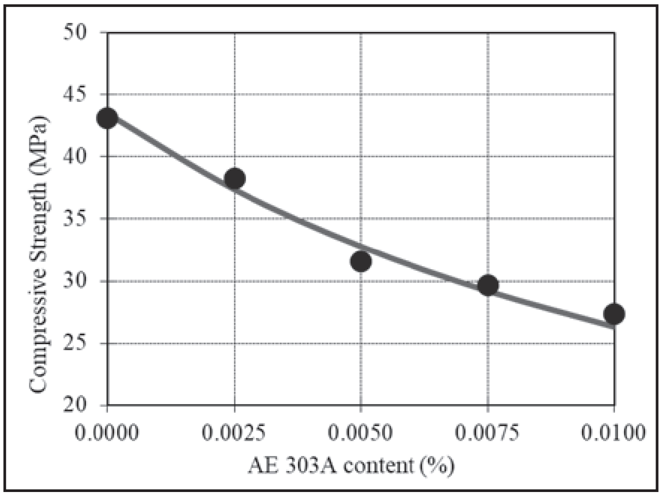

Fig. 4.Relationship Between 7 days Compressive Strength and the Content of Air Entrained Agent

The relationship between the 7 days compressive strength and air entrained agent content is empirically represented by equation 3.

$$f_c = \frac{1}{(C_5 A_e + C_6)} \quad (3)$$

Here, f_c is the compressive strength; C_5 is the constant depending upon the efficiency of AE agent. Its value was 1.5 for the trend analysis of the curve. C_6 is the constant depending upon properties of ingredients, mix proportion as well as compaction, and curing condition. Its value was 0.023 in this analysis.

Fig. 5 and 6 are additional trend graphs of the relation of air content with 7 days hardened density and compressive strength respectively. These graphs tentatively verify that both density and compressive strength of mortar are inversely proportional to its air content with same trend of decreasing compressive strength while increasing the air content of the mortar. Since the air content depends upon the content of AE agent, empirical analysis of the effect of air content on hardened density and compressive strength is not done. The solid lines given in both the graphs are just the regression linear lines showing the decreasing trend while increasing the air content.

The result obtained from this research work was only for one specific high efficient air agent, AE303A. So, it is still pre-mature to conclude that this result may be applicable for different types of highly efficient air

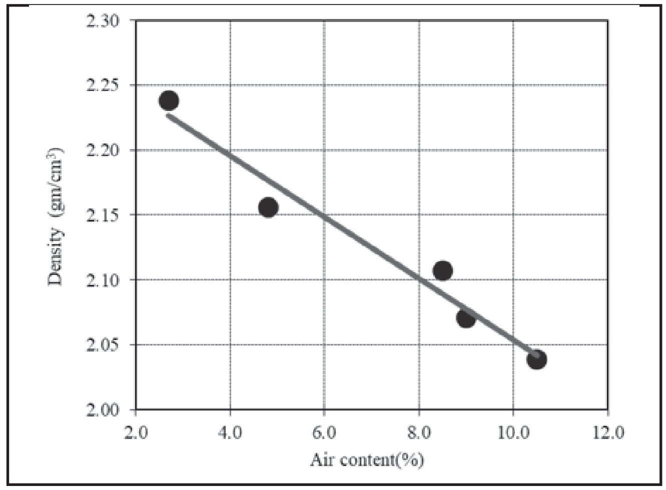

Fig. 5. Relationship Between Hardened Density and Air Entrained Agent Content

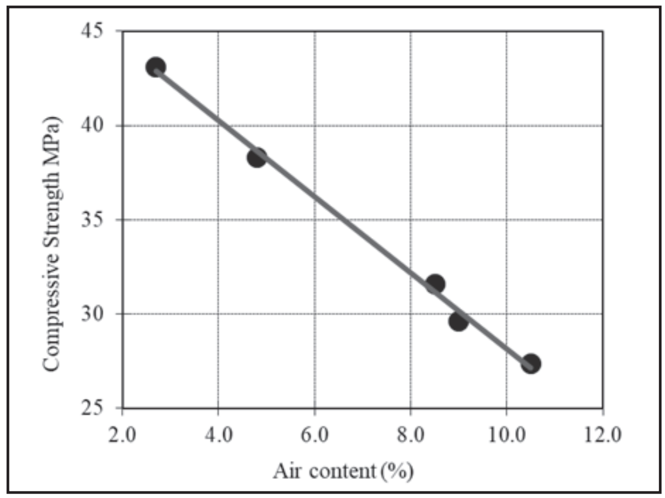

Fig. 6. Relationship Between 7 days Compressive Strength and Air Content of Mortar

agents available in markets of different countries. Therefore, future research work should be concentrated on standardizing the relationship mentioned in this paper, focusing on the chemical composition of the available air agents.

VI. CONCLUSION

The most important conclusion drawn is that the use of highly efficient air entrained agent AE 303A does not enhance the workability of mortar. Other conclusive points are:

- Air content increases the trend of power curve while increasing the AE agent.
- Hardened density of mortar decreases with the trend

of exponential curve while increasing the AE agent.

- Compressive strength of mortar also decreases with exponential trend with increase of the AE agent.
- Both density and compressive strength have decreasing linear trend with increasing air content. However, the air content is highly dependent on the content of AE agent.

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CONFLICT OF INTEREST

The author declares that there is no interest of conflict.

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