Effect of Air-entrained Agent for the Mortar of Roller Compacted Concrete

Tek Raj Gyawali[1*]

[1]Professor (Ph.D.), School of Engineering, Faculty of Science and Technology, Pokhara University, Pokhara Metropolitan City-30, P.O. Box 427, Kaski, Nepal;

* Corresponding email: tekrg@pu.edu.np; Orcid number: 0000-0001-9900-2513

Abstract

Roller compacted concrete (RCC) is the zero slump concrete produced from the same materials used in conventional concrete. The mortar used in RCC plays a significant role for the workability, strength and durability of the concrete. The air content in the mortar is the key factor for durability, especially to resist the freezing and thawing action. The main target is to produce the microscopic air cells inside the mortar using air-entrained agent and minimize the entrapped air as little as possible. Air content may range from 4~7% depending upon the type of concrete. The effect of the content of AE 303A type air-entrained agent was studied for the fresh and hardened properties of the RCC mortar. The result showed that it has an almost negligible effect on the workability of mortar, but highly effective for the density and compressive strength of hardened mortar. The use of 0.02% (by weight of cement) increased the air content about 4.5 times of the base mortar (without the use of the agent), from 2% to 9.1%. However, the density was decreased by about 10 % (from 2.18 gm/cm^3 to 1.96 gm/cm^3) and the 28 days compressive strength by about 49% (from 21.90 MPa to 14.73 MPa). The model, developed for the mortar of the dam concrete, has also been well satisfied with the experimental results for the case of RCC mortar.

Keywords: *Air content, Air-entrained agent, Compressive strength, Hardened density, Mortar, Roller compacted concrete (RCC)*

Introduction

Roller compacted concrete (RCC) is defined as the zero-slump concrete which should be compacted with vibratory and rubber-tired rollers (Mardani-Aghabaglou et. al, 2013). Roller compacted concrete (RCC) is generally used in dams, road pavements, and airport runways as mass concrete because it is cheaper to produce and easier for the placement and compaction (Pigeon & Malhotra, 1995; Gao et. al, 2006; Yerramala & Ganesh Babu, 2011). It is produced with similar materials of normal concrete. Its workability is judged by the compaction factor or VeBe time tests. The strength of RCC is required to investigate under environmental loading and its long-term durability under critical circumstances. An appropriate amount of microscopic air voids should be uniformly distributed, under discrete conditions, to secure the durability of RCC especially under the freezing and thawing action (Lee et. al, 2011). It was found from field experiments that RCC with good composition with appropriate casting and curing process resists the frost and also has the capacity to resist the salt frost resistance if mineral admixtures are added (Pigeon & Marchand, 1996; Piggott, 1999; Hazaree et. al, 2011; Hazaree et. al, 2015).

There are billions of microscopic air cells per cubic foot in the air-entrained concrete. These air cells relieve internal pressure on the concrete by providing tiny chambers for water to expand into when it freezes; and it usually causes the porosity to increase, thereby decreasing the strength of concrete(Portland Cement Association, 2021). Besides the decrease of strength, air voids have the benefit of increasing durability with resisting freezing and thawing. It also increases the workability with the control of bleeding and segregation problems (Olanike, 2013). It was also verified by another author that the use of the air-entrained agent enhances the concrete for the freeze-thaw durability (Shang & Yi, 2013). It is also warned that the excess use of the air-entrained agent has negative effects for both strength and durability (The Aberdeen Group, 1976). The use of air-entrained agents may decrease the ingredients, making the concrete more economical with enhancement on durability (Shalem & Pandey, 2015). It also reduces the water required to obtain the desired workability which may increase the strength (Bugg 1947; Gridhar 2013).

Most of the researchers have claimed that the use of air-entrained agents increases workability and reduces the segregation and bleeding of fresh concrete (Dolch 1984; Pigeon 1987; Whiting & Dziedzic 1990; Rixom & Mailvaganam 1996). However, recent research has shown that the use of highly efficient air-entrained agents has a significant effect to increase the air content without altering the workability of dam concrete mortar (Gyawali, 2019).

The use of air-entrained agent, in concrete, is become vitally important to enhance the durability of concrete structures, especially for the purpose of resisting the freezing and thawing action. Now, it is become common practice in the world. However, Nepalese construction industries are lagging behind to adopt and implement the concept of air content in the concrete structures. That is one of the reason why the concrete structures have the severe problems of deterioration with short span of the durability. Thus, author hereby has intended to focus on the use of air-entrained agent to maintain the air content in the concrete. It should be noted that the air content should only be due to the entrained air bubble and the entrapped air should be minimized as little as possible.

Objectives

The main aim of this research work is to investigate the effectiveness of high efficient AE 303A type air-entrained agent for the fresh and hardened properties of RCC mortar. Its specific objectives are:

(1) To check the effect of the content of the air-entrained agent for the workability, air content, hardened density, and compressive strength of RCC mortar. Also, draw the relationship of air content with hardened density and compressive strength.

(2) To check if the empirical model, developed for the mortar of the dam concrete, may also be applied for the RCC mortar.

Experimental Procedure

Table 1 gives the mix proportions of the RCC mortar. Chemical admixtures were considered as part of water with specific gravities of 1.0. Ordinary cement, with its specific gravity of 3.15, was used. The crushed type sand with a specific gravity of 2.64 was used. The main parameter was the content of AE303A varying with 0%, 0.0075%, 0.0100%, and 0.0200% by weight of cement. No. 70 type chemical admixture was used to enhance the workability of mortar. Its content was 0.25 % by weight of cement for all series of experiments.

Table 1: Mix proportion of RCC base mortar

Concrete Mix Type	Mix Proportion Condition		Unit Content (Kg/m^3)				
	W/C (%)	S/C	W	C	S	Chemical Admixtures	
						No. 70	303A
RCC mortar	61.8	3.1	270	437	1374	1092	Varying
W: Water, C: Cement, S: Sand, No. 70: AE admixture, 303A: High efficient air-entrained agent							

The 10 liter capacity mortar mixer was used for mixing the mortar. Its revolving speed was low, medium and high. The volume of each batch of mortar was 10 litres. At first, the moisture content of sand was stabilized in the floor by two people using shovels. It was done by mixing the sand using shovels 6 times from one end to another. Then the moisture content of the sand was measured. All ingredients were measured by weight for a 10 litre batch. The weight of sand was adjusted with the consideration of moisture content and the water was adjusted with moisture content as well as the amount of chemical admixtures.

The batched chemical admixtures were pre-mixed with water by stirring with the spoon in the bucket. A first-half portion of sand was charged into the mixer followed by the full amount of cement and then the remaining portion of sand making the sand witched layers. The mix was mixed in a dry condition for 30 seconds with low speed. Then water was charged part by part while mixing in a low speed. After the finish of charging water, wet mixing was carried out for 60 seconds. The mixer was stopped and checked if any unmixed particles remaining on the inner surface and bottom. Finally, the mixing was done with high speed for a further one minute. A similar mixing procedure was adopted for each batch of mixing.

After the finishing of mixing, the bowl of the mixer was detached and placed on the floor. The ambient and mortar temperature were measured before carrying out other fresh tests. All tests were carried out in accordance with Japan Industrial Standard (JIS) methods. Table flow (JIS 5201 2015) and air content (JIS A 1116 2005) tests were carried out to judge the quality of the mortar. Since this series of experiments was for the comparison study, 6 numbers of φ5mm × 10 mm cylinders were prepared for 7 days compressive strength test JIS 1107). The specimens were air-cured for 24 hours. Then the cylinders were demoulded and then water cured. The density of hardened mortar and the compressive strength tests were carried out in 7 days.

Test Results

Table 2 gives the properties of the fresh mortar.

Table 2: Summarized result of the fresh properties of RCC mortar

AE Content (%)	Ambient Temperature (0C)	Mortar Temperature (0C)	Air Content (%)	Table Flow: No Tamping (mm)	Table Flow: 15 Times Tamping (mm)
0.0000	31.5	30.5	2.0	155	246
0.0075	31.5	30.5	6.3	156	248
0.0100	31.5	30.5	7.1	173	260
0.0200	31.5	30.5	9.2	159	250

Both the ambient and mortar temperature data show that all experiments were conducted in the same environmental condition. Moreover, there was no big difference between the ambient and mortar temperature. The air content of the base mortar, without the use of AE 303A, was only 2.0%. It increased drastically while introducing small content of AE 303A and it was 9.2% with 0.02% of AE 303A (by weight of cement). However, there was no big difference on the table flow value (both in the case of zero and 15 times tamping). Table 3 shows the result of the hardened properties of RCC mortar.

Table 3: Hardened properties of RCC mortar

AE 303A Content (%×C)	Hardened Average Density (gm/cm3)	Variation Coefficient (%)	Average Compressive Strength (MPa)	Variation Coefficient (%)
0.0000	2.18	0.26	21.90	0.91
0.0075	2.04	0.14	17.37	4.47
0.0100	1.99	0.26	15.23	1.55
0.0200	1.96	0.00	14.73	4.24

Average values of the 7 days hardened density and compressive strength of 6 cylinders are shown in the table. Since the variation coefficients in each set of data are within the margin, the quality adopted in each set of experiments was under control. It is shown from the result that the introduction of AE303A into the mortar reduces both hardened density and compressive strength. The density and compressive strength of mortar, without the use of AE 303A, were 2.18 gm/cm3 and 21.90 MPa respectively. However, while using 0.0200% of AE 303A, both density and compressive strength were obtained 1.96 gm/cm3 and 14.73 MPa respectively. The trend of both densities and compressive strengths was found in decreasing order while increasing the content of AE 303A.

Analysis and Discussions

The relation between table flow value and the air-entrained agent content is shown in Figure 1. The trend of the graph clearly shows that no significant difference was noticed in the workability of mortar while increasing the content of AE 303A. The flow values were almost constant with a range of 245 mm to 260 mm and with no trend of increasing or decreasing order which satisfies the target of 250±20 mm.

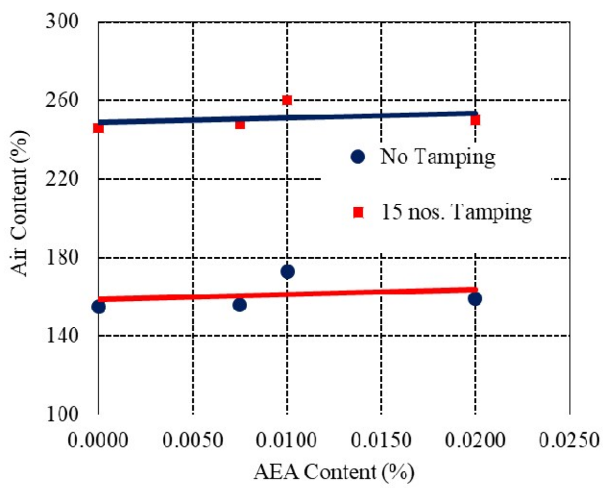

Figure 1: Relation between the content of AE 303A and table flow value

The use of very high-efficiency AE 303A produces microscopic air bubbles uniformly inside the mortar in discrete order. Since the amount of AE 303A is significantly small with respect to the amount of water, AE 303A has a negligible capacity to make the water particles lubricant. Thus, the use of AE 303A has not a noticeable effect on the enhancement of the workability. It was the main reason on using 0.25% of AE No. 70 admixture, by weight of cement, to enhance the workability of mortar. The relationship between the content of AE 303A and the air content is shown in Figure 2. The graph clearly shows that the introduction of very small amounts of AE 303A has significantly increased the air content. Also, the increase in the dosage of AE 303A has increased the air content non-linearly as shown in the figure.

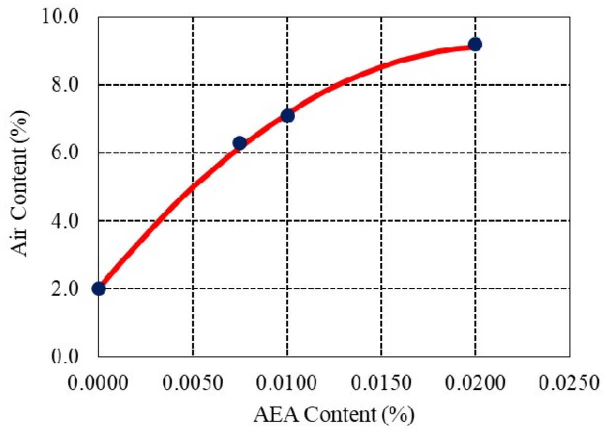

Figure 2: Relationship between air content and air-entrained agent content

The following model developed for the case of dam mortar (Gyawali 2019) has also matched with these experimental data for the case of RCC mortar.

$$A_c = C_1 {A_e}^2 + C_2 A_e + C_3 \ldots\ldots\ldots\ldots (1)$$

To match the experimental data perfectly, the values of coefficients C1, C2, and C3 were taken as 16000, 675, and 2. It was revealed from the comparative study that the effectiveness of the AE 303A is lesser for RCC mortar than in the case of the dam mortar. For the cases of RCC mortar, more than the double dosage of AE 303A was required to produce the same level of the air content as in the dam mortar. It was understood from this comparative study that the increase of the W/C ratio in mortar decreases the effectiveness of the AE 303A. Figure 3 shows the relationship between the content of AE 303A and 7 days hardened density of the mortar.

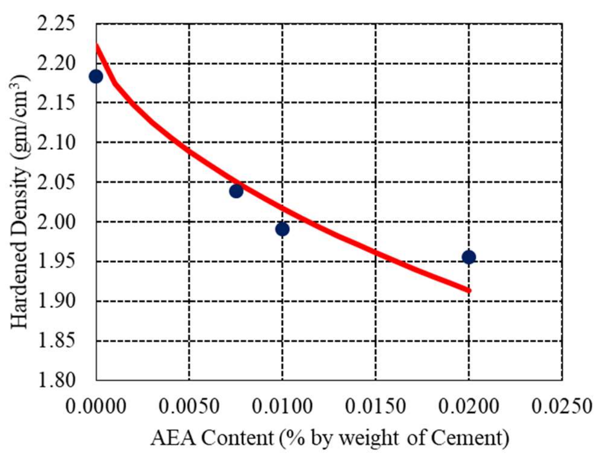

Figure 3: Relation between the 7 days hardened density of mortar and air-entrained agent content

Equation 2, developed for the dam mortar has also tentatively matched the experimental data for the RCC mortar. γ_h represents the density of hardened mortar. C4 is the constant depending upon the properties of ingredients, mix proportion and compaction condition.

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

The value of C4 was 0.45 in this analysis.
The relationship between the content of AE 303A and the 7 days compressive strength is shown in Figure 4.

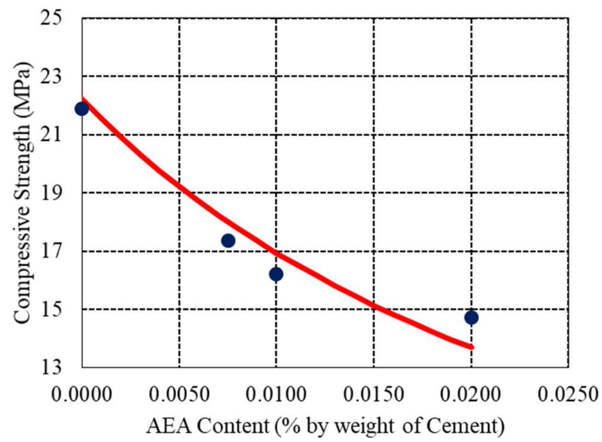

Figure 4: Relationship between the content of AE 303A and 7 days compressive strength

The following equation model, developed for the dam mortar, has also satisfied the experimental data for the RCC mortar.

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

Here, f_c represents the 7 days compressive strength. Values of C_5 and C_6 are material constants. C_5 depends upon the efficiency of AE agent and its value was taken as 1.4 for the case of RCC mortar. C_6 depends upon properties of ingredients, mix proportion as well as compaction and curing conditions. Its value was 0.0045 in this analysis.

Figure 5 represents the relationship of the density with air content. The graph has shown that the hardened density of mortar linearly decreases with the increase in the air content. The equation model is not required for this relationship since it can be obtained with the combination of **equations (1)** and (2).

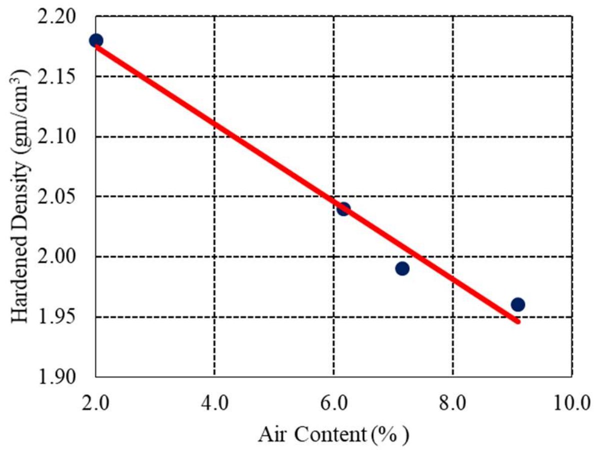

Figure 5: Relation between the air content and hardened density of the hardened mortar

Figure 6 gives the relationship of the compressive strength with the air content of the RCC mortar. The similar trend is achieved as in Figure 5. Its equation model can also be achieved with the combination of **equations (2)** and **(3)**.

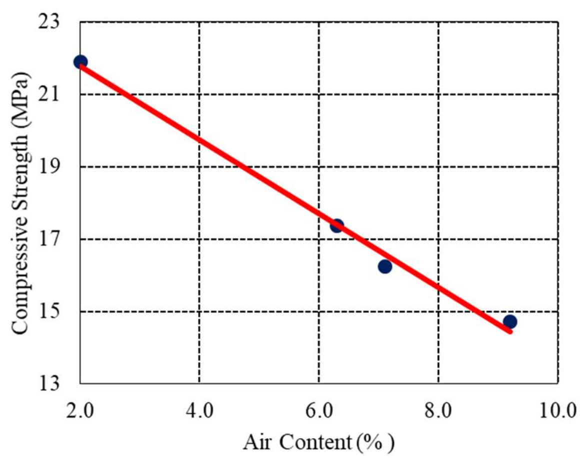

Figure 6: Relation between the air content and compressive strength of RCC mortar

The relation of the compressive strength with the hardened density of RCC mortar is shown in Figure **7**. The graph has proved that the compressive strength of the mortar is linearly proportional to the hardened density. Its model can be achieved with the combination of **equations (1)** and **(3)**.

The result obtained from this research work for the RCC mortar has given a similar trend to that of dam mortar. The model developed for the dam mortar has worked well with RCC mortar. It gives the direction to generalize the model with the experimental data for other mortars of various types of concrete.

Conclusion

The followings are the major conclusive points drawn from this research work.

- AE 303A has a negligible effect on the workability of RCC mortar. Other chemical admixtures, like water retarder, plasticizers and superplasticizers are required to enhance its workability,
- The use of a very little amount of AE 303A drastically increases the air content of RCC mortar and air content increases non-linearly with the increase of the AE 303A as given in the model.
- Due to an increase in the air content, both the hardened density and compressive strength of RCC mortar decrease exponentially with an increase of AE 303 A.
- Both the hardened density and compressive strength of RCC mortar have the trend of linearly decreasing with an increase of the air content.
- The model developed for the mortar of the dam concrete has also worked for the RCC mortar.

All experimental data of RCC mortar have given a similar trend of results with those of dam mortar and the model has worked for both. Thus, many further experimental works, using different types of air-entrained agents, are required for other mortars of different types of concrete to generalize the model. The author hereby has claimed that the new result that the small content of high efficient air entrained agent significantly increases the air content without altering the workability. Moreover, the claim made by previous research works (Dolch 1984; Pigeon 1987; Whiting & Dziedzic 1990; Rixom and Mailvaganam 1996) as "use of air-entrained agent increases the workability" does not work for the case of high efficient air-entrained agents. In general conclusion, the introduction and implementation of such high efficient air-entrained agents, for concrete, may enhance the quality of structures in durability aspects.

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