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Effect of Air Entrainment on Compressive Strength, Density, and Ingredients of Concrete

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ABSTRACT: *The micro air bubbles in concrete mix act as fine aggregates which lead to reduction of the aggregates. The reduction of fine aggregates will cause reduction of water required for concrete mix without impairing the strength of concrete mix. This reduction has to be considered in designing an air entrained concrete mix. Theoretical (equations) and experimental study have been carried out to study the effect of air entrainment on compressive strength, density and ingredients of fresh concrete mix. During all the study, water cement ratio (w/c) was maintained constant at 0.5 to study the affection of air entrainment (a %) on concrete mix. The results have shown substantial decreasing in cement, water, aggregates and concrete density followed with decreasing in compressive strength of concrete. The results of this study has given more promising to use it as a guide for concrete mix design to choose the most appropriate concrete mix design economically.*

Keywords: *About five key words in alphabetical order, separated by comma.*

I. INTRODUCTION

Air entrained concrete consider one of the important discovery made in concrete technology. Since 1930 after the recognition of the merits of air entrained concrete, the use of such concrete increases all over the world especially in United States and Canada [1]. About 85 percent of the concrete manufacture in America contains air entraining agent. The air entraining agent consider as fifth ingredient in concrete making technology.

Air entrained concrete is made either by using air entraining cement or by mixing a small quantity of air entraining agent. These airs entraining agent produce millions of micro air bubbles inside the concrete mix acting as flexible ball bearings. The micro air bubbles of size ranging from 5 microns to 80 microns distribute in the entire mass of concrete resulting in modification of the properties of it regarding workability, segregation, bleeding and finishing quality [3].

Since the air bubbles form in water, the lower w/c ratio of the paste the hard to entrain air in the paste. On the other hand, the higher w/c ratio of the paste, the small air voids can easily become large ones and then escape from the paste. It has been reported that increasing of w/c ratio leads to increases in the spacing in hardened concrete and the air void system become worse [4].

The characteristics and grading of aggregates have also significant influence on air entrainment. In mortar and concrete, the fine aggregates can form a space to hold the air bubbles and prevent them from escaping. Furthermore, aggregate with a sharp shape, like crushed stone, will entrain less air than gravel. The sharper the aggregate is the harder for the air bubbles to attach on it [5].

Entrained air has major impact on water-cement ratio. Air entrained concrete can have lower water-cement ratios than non-air-entrained concrete; this minimize the reductions in strength that generally accompany and related to air entrainment [6].

II. METHODOLOGY (STUDY METHOD)

The methodology for studying the effect of air entrained on concrete mix is based on theoretical equations. These equations were derived from required water absorption and from volumetric equation which widely used in concrete mix design with some assumptions. By using these equations, verity of concrete proportions data can be generated. The theoretical results of concrete proportions data was carried out experimentally to perform concrete mixes design and to plot the relationship between the air entrainment and concrete compressive strength. By using this relationship, a guideline for a variety of concrete compressive strength will all of concrete proportions can be presented. The following is the assumptions and the equations used in this study.

1.1 Assumptions:

- ρ_c = (Specific gravity of cement) = 3.1.
- W_c = (The rate of required water to cement for complete paste hydration) = 0.23
- ρ_A = (Specific gravity of aggregates) = 2.7
- W_{An} = (Max absorbed water required by weight of aggregates) = 2%
- W_A = (available water for aggregates absorption and concrete workability) = 0.04
- C/W = (the rate cement to water) = 2.0
- a = (Air entrainment as percentage) = 0 – 8%

1.2 Equations:

- $\frac{C}{\rho_C} + \frac{A}{\rho_A} + W + a = 1000$ (volumetric equation) where
  C = cement, A = Aggregates, W = water

- $W = C * W_C + A * W_A$ (water absorption equation)
  By combining the previous equations we get

- $\frac{C}{\rho_C} + \frac{A}{\rho_A} + C * W_C + A * W_A + a = 1000$
  From the above three equations, we get

- $C = \frac{(1000 - a\% * 1000) * W_A}{(0.553 + b) * w_A + (\frac{1}{\rho_A} * b)}$

- $A = \frac{(1000 - a\% * 1000) - C * (\frac{1}{\rho_C} + W_C)}{\frac{1}{\rho_A} + W_A}$ (where $b = \frac{W}{C} - 0.23$)

III. STUDY PROGRAMS

1. Theoretical study

By using the previous equations and assumptions with verity values of air entrainment, a Table with variable concrete proportions data can be generated as follows.

Table (1) Generated Densities and Proportions of Concrete Mix Based On Air Entrainment

Air Entrainment %	Cement (kg/m^3)	Water (dm^3/m^3)	Aggregates (kg/m^3)	Density (kg/m^3)
0	301	150	2031	2483
1	298	149	2011	2458
2	295	147	1991	2433
3	292	146	1971	2409
4	289	144	1950	2383
5	286	143	1930	2359
6	283	141	1910	2334
7	280	140	1889	2309
8	277	138	1869	2284

2. Experimental study

From the previous Table, twenty four specimens were prepared based on different air entrainment values (a %) to perform compressive strength tests procedure as follows.

- Twenty four concrete specimens with variable (a %) values were prepared (Table (1))
- Cubic moulds were filled in 3 layers, each approximately 1/3 of the height of the moulds
- Each layer was stroked 25 times by the stroking rod all over the cross section of the layer
- After the top layer was stroked, a trowel and stroking rod used to smooth the concrete surface level
- The specimens were cured in water tank for 28 days
- Compressive strength studies were carried out on the specimens using compressive strength machine
- A Table (1) contains all the compressive strength values of the concrete mixes were presented

Table (2) Realtionship between Air Entrainment, Compressive Strength, Density, and the Proportions Of Concrete Mix

Air Entrainment (%)	Cement (Kg/m$^{3)}$	Water (Kg/m$^{3)}$	Aggregates (Kg/m$^{3)}$	Density (Kg/m$^{3)}$	Compressive Strength (kg/cm$^{2)}$
0	301	150	2031	2438	300
1	298	149	2011	2458	275
2	295	147	1991	2433	253
3	292	146	1971	2409	234
4	289	144	1950	2383	216
5	286	143	1930	2359	200
6	283	141	1910	2334	186
7	280	140	1889	2309	173
8	277	138	1869	2284	161

IV. RESULTS AND DISCUSSION

From the Table (1) the increasing in air content can decrease all the proportions of concrete by variable values. This influence on concrete ingredients can be plotted as graphs from which a guideline for air entrainment can be presented. Figure (1) shows the effect of air entrainment on cement content per cubic meter in concrete mix. Figure (2) shows the influence of air entrainment on water content in fresh concrete mix while Figure (3) and Figure (4) illustrate the relationship between entrained air with aggregates and density of concrete respectively. Figure (5) illustrate the significance of reduction especially in higher strength mixes. All the reduction of proportions of concrete caused by increasing of air content can be graphed as shown below.

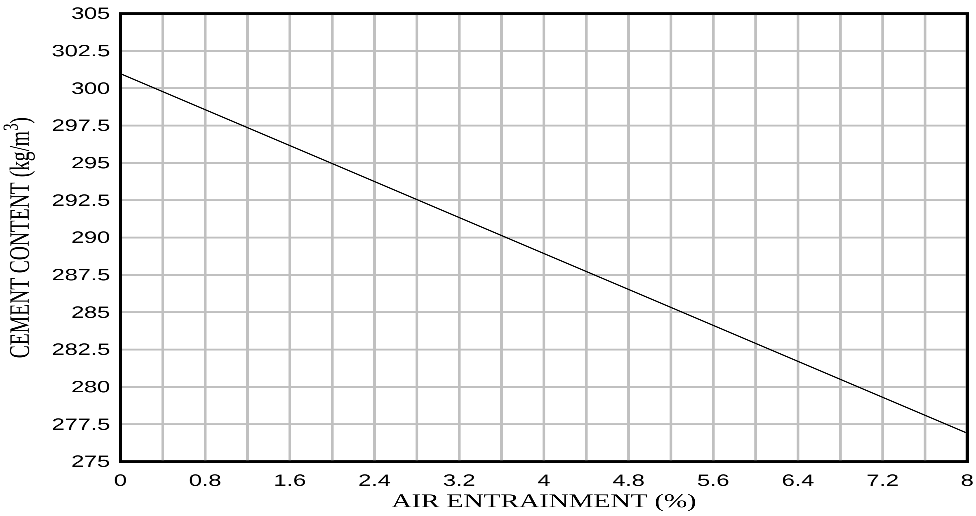

FIGURE (1) EFFECT OF AIR ENTRAINMENT ON CEMENT CONTENT OF CONCRETE MIX

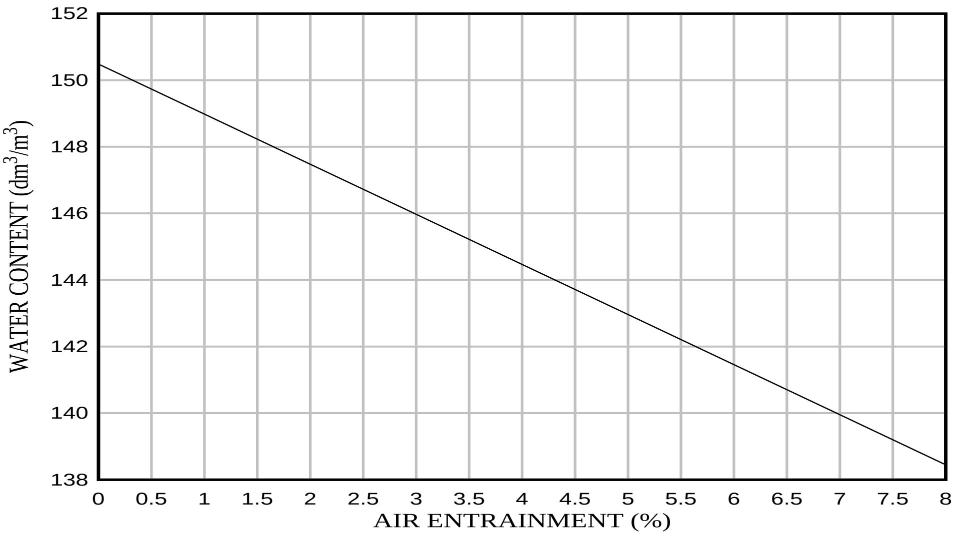

FIGURE (2) EFFECT OF AIR ENTRAINMENT ON WATER CONTENT OF CONCRETE MIX

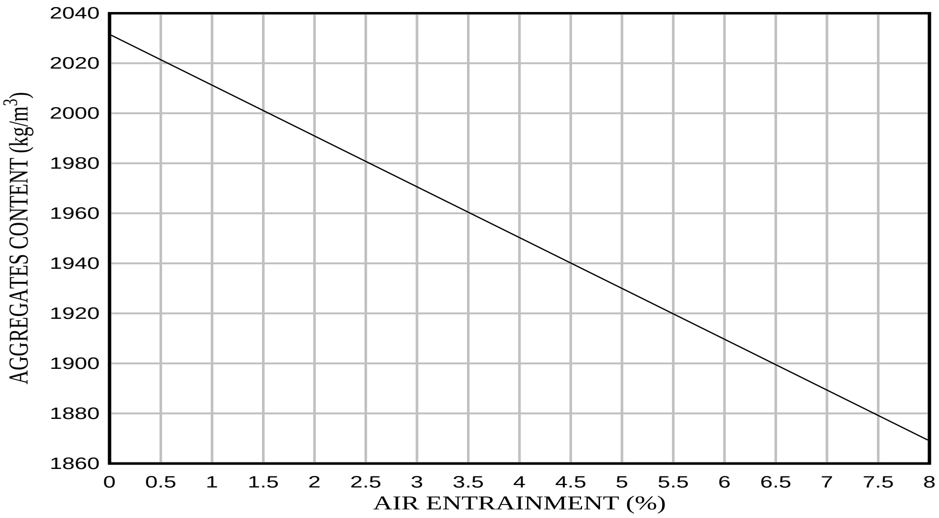

FIGURE (3) EFFECT OF AIR ENTRAINMENT ON AGGREGATES CONTENT OF CONCRETE MIX

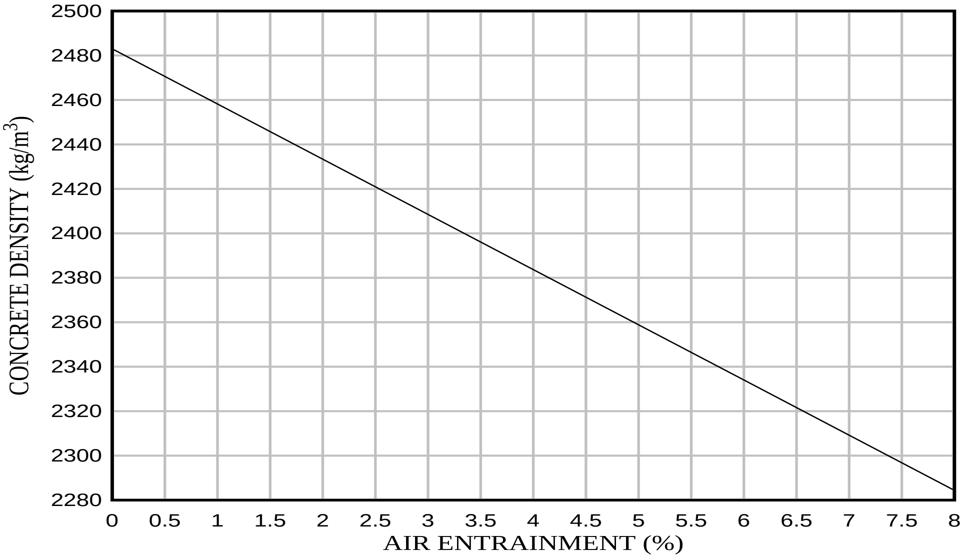

FIGURE (4) EFFECT OF AIR ENTRAINMENT ON DENSITY OF CONCRETE IN CONCRETE MIX

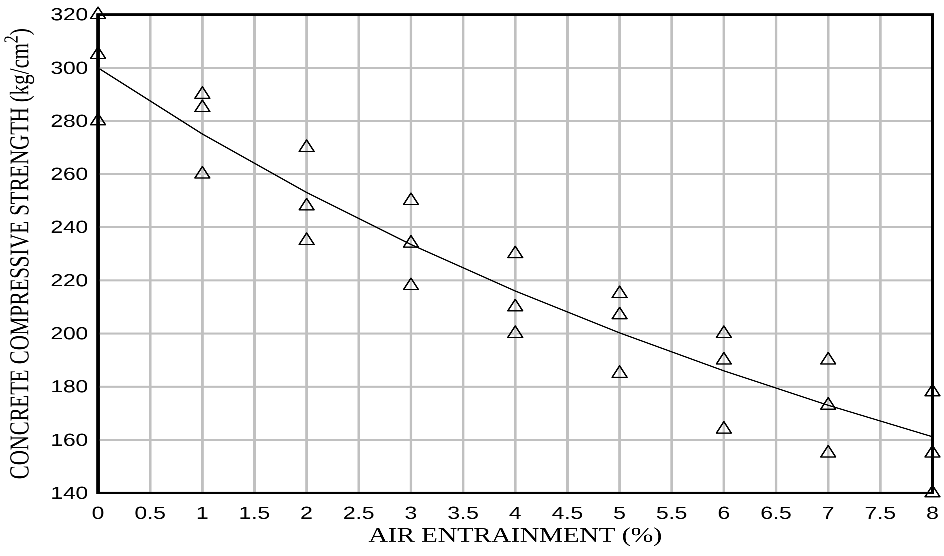

FIGURE (5) EFFECT OF AIR ENTRAINMENT ON COMPRESSIVE STRENGTH OF CONCRETE IN CONCRETE MIX

From the previous Table and Figures, effect of air entrainment on ingredients of concrete mix is clearly causing reduction on these components. The reduction value is variable for each component by each percent increasing in air entrainment.

- Reduction in aggregates content by 20.25 kg/m^3 weight for each percent increasing in air entrainment
- Reduction in water content by 1.5 kg/m^3 weight for each percent increasing in air entrainment
- Reduction in concrete density by 24.875kg/m^3 weight for each percent increasing in air entrainment
- The cement content in the concrete mix is reduced by 3 kg/m^3 for each percent increasing in air entrainment
- Reduction in concrete compressive strength by 12.5kg/m3 weight for each percent in air entrainment
- Reduction in strength become more significant in higher strength mixes
- The workability and the slump of the concrete remain without any impairing due to the increasing of air entrainment since C/W and W_A were constant during all the testing calculations.

V. SUMMARY AND CONCLUSION

It has been studied the effect of air entrained on aggregates, water, and cement content in fresh concrete mix. It was noticed that the air bubbles which generated by using either special type of cement or by using an air entrainment agent distributed in the entire mass of the concrete acting as flexible ball bearings. These flexible balls act as a fine aggregate as well which cause reduction in the aggregates followed by reduction in the water and cement content as result of this reduction. The workability (slump test) in concrete mix remains without changing due to the increasing of air entrainment since C/W and W_A are constant. The conclusion of this study can be summarized as following.

- The air entrainment is necessary in concrete mix design and it can consider fifth proportion.
- The air entrainment can reduce the ingredients of concrete without any effect in the workability of the concrete mix which mean more economical concrete mix can be achieved by using air entrainment agent whoever decreasing of concrete compressive strength by increasing of air entrainment should be considered.
- The reduction of cement due to the increasing of air entrainment in the concrete mix result in a lower heat of hydration in mass concrete (dams as example). The decrease in temperature due to the hydration process result in reduction in cracking and any undesirable internal stresses.

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