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The Effect of Quantity of Cement and Mixing Water on Strength and Durability of Concrete

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Abstract- Design and construction of concrete structures are primary based on two major considerations: strength and durability. In order for structures to attain their anticipated serviceability, they should be able to resist both the effect of externally applied loads and the influence of environmentally-induced deterioration agents, including the ingress of moisture which is one of the primary causes of corrosion of embedded steel bars in concrete. There are, however, some constraints that limit the capability of concrete structures to perform their intended purpose. Many structures – no matter – how elegantly built suffer premature damage and deterioration due to either substandard materials used in the construction or faulty construction methods and practices. Concrete, being a composite material, is made by combining several ingredients in order to form into a solid mass, and the two primary ingredients are water and cement which must require certain proportion to produce a strong and durable structure. This study centers on the effect of quantity of cement and mixing water on the strength and durability parameters of hardened concrete. More particularly the slump, compressive strength and rate of capillary absorption were investigated experimentally using three types of concrete of varying cement and mixing water quantities. The result showed that using more amount of water and less amount of cement in the concrete mix lessens its strength and, at the same time, increases its vulnerability to deterioration.

Keywords- *strength, durability, environment, sorptivity, deterioration*

I. INTRODUCTION

Concrete is the most widely used construction material in the world today due to the abundance of the ingredients used in its production, its inherent strength and durability, its affordability, and the fact that it can be readily made into desired architectural form and shape [1]. In the Philippines, almost 95% of its significant structures are made of concrete for the very reason that all of its ingredients (water, cement, sand and gravel) can be found all over the archipelago at prices that even a low-income family can afford [2].

Concrete, a composite by-product, is produced by mixing hydraulic cement, water, sand and gravel (called aggregates) with or without admixture, which, upon chemical reaction between cement and water, results to a solid mass of material with properties different from the original properties of its ingredients [3]. In order to produce a concrete with good quality, the amount of mixing water to be used should be controlled to certain quantity in order to attain the desired strength and durability of the finished product. However, the current local practice of mixing concrete which is based on "Class" method (e.g., Class AA, A, B, C and D) does not include the amount of water to be used in a certain batch of mix [4]. For instance, a "Class A" mix (which descriptively means 1: 2: 4) only tells us that we need to mix 1 part of cement, 2.parts of sand and 4 parts of gravel by volume, without specifying the amount of water.

Studies have shown that excessive use of water in the mix is not beneficial to concrete [5], but its effect and relationship to strength and durability is yet to be conducted locally. The purpose, therefore, of this study is to quantitatively determine the effect of the amount of mixing water in relation to the given amount of cement (called water-cement ratio) on the slump, compressive strength and absorption capacity of concrete. The result of this study will contribute to the attainment of proper design and construction of reinforced concrete structures that will last longer and serve its intended purpose, hence lessening its maintenance cost.

II. MATERIALS AND METHODS

A. General

The materials used in this study consist of cement, sand and gravel, all of which were sourced out from local suppliers in Borongan City, Eastern Samar. Cement used was ordinary Portland cement (OPC), Type 1, and in accordance to ASTM C150-07 [6]. The aggregates used consist of mineral sand and gravel. Immediately after the purchase, all materials were stored in a clean and dry place in the ESSU Engineering Laboratory. Cement was placed inside an airtight plastic container to prevent intrusion of moisture. Prior to fabrication of specimens, sand was sieved in accordance to ASTM C33-07 [7] using 0.3mm – 0.86 mm (#50 - #18) sieve, while gravel was graded using 12.5 mm – 19.0 mm (Size #6) sieve. The primary purpose is to obtain a uniform and consistent mix.

These aggregates were first washed with clean water to remove impurities and then air-dried prior to their use.

In this study, three types of cylindrical specimens measuring 100 mm diameter and 200 mm high (4" ϕ x 8" high) of varying water-cement ratios (0.40, 0.55 and 0.70) were used. The concrete mix design was done in accordance to ACI 211.1-91R02 (also known as the Absolute Volume Method) [8] which considers a weight basis for proportioning concrete ingredients and mixing, sampling and curing fresh concrete was also done in accordance to approved ASTM Standards [9,10].

B. The Slump Test

The objective of this test is to determine the workability and consistency of the mix in terms of amount of water and distribution of ingredients in the concrete mix. This test was done in accordance to ASTM C143-08 [11]. Immediately after the concrete mix was discharged from the mixer, the fresh concrete was placed in a conical vessel where the slump was measured [10].

C. The Compressive Strength Test

The objective of this test is to determine the compressive strength of concrete at 28 days age. The standard test procedure used was ASTM C617-03 for sulfur capping [12] and ASTM C39-01 for the compressive strength [13]. After the 28-days curing period, the specimens were retrieved from the curing pond and were air dried for 6 hours prior to testing. In order to get a statistically reliable result, at least three samples were tested for each batch of mix.

D. The Sorptivity (or Capillary Absorption) Test

This test was conducted to determine the rate of water absorption of the concrete and its tendency to absorb and transmit water by capillarity [14]. The test used here was in accordance to RILEM II-6 [15], a European standard used to determine the water absorption capacity of concrete. This procedure is recommended due to its simplicity and reliability of result.

III. RESULTS AND DISCUSSION

A. Slump of Concrete

The slump values of the three concrete specimens is shown in Fig. 1. The result shows that adding more water to the concrete mix significantly increases the value of slump. In fact, a unit increase in water-cement ratio increases the slump by more than two times. This means that for each bag of cement used, increasing the amount of water by 37% will result to a 93% increase in slump on the average.

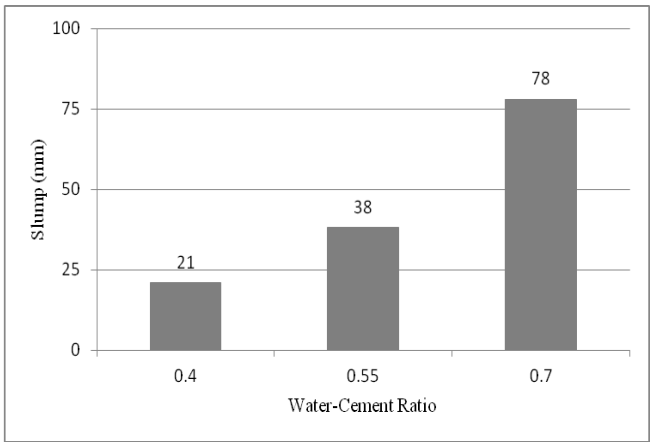

Figure 1. Effect of Water-Cement Ratio on Slump of Concrete

Likewise, the increase in slump is further magnified with the addition of more water to the mix. This is emphasized by an increased slope of the line between w/c 0.55 to 0.70 in Fig 2.

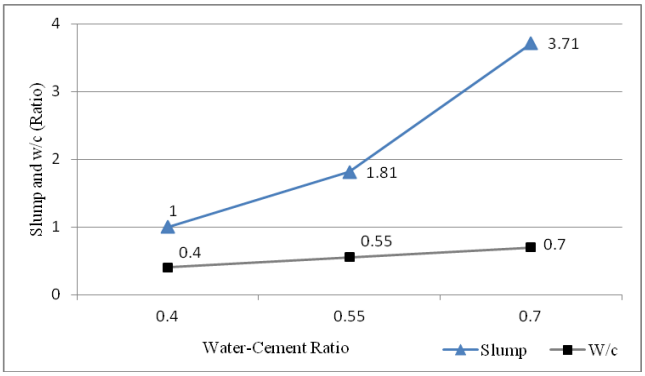

Figure 2. Comparison between Water-Cement Ratio and Slump in Concrete

While increasing the amount of water in the mix will result to a more fluid concrete which is very easy to mix manually, the detrimental effect to this would be bleeding on forms which will result to honeycombing and weaker concrete.

B. Compressive Strength of Hardened Concrete

The result of compressive strength test of concretes after 28 days, is shown in Fig. 3. As shown, a slight increase in water-cement ratio results to more abrupt reduction in strength. Specifically, a 37% increase in water in the concrete mix will result to a 54% decrease in compressive strength on the average. While it is true that mixing concrete with more water is more convenient in terms of labor, its consequence can be very dangerous to structure because of the reduction of its compressive strength.

C. *Sorptivity (Absorption Capacity) of Concrete*

The result of capillary absorption test on the 3 specimens is shown Fig. 4. Based on the figure, the absorbing capacity of concrete increases with the increase of w/c, although lesser in incremental values when compared with the slump and compressive strength results. This means that the more water used in mixing concrete, the greater is the capacity of hardened concrete to absorb external water. This will result to faster deterioration of the structure especially when the water being absorbed by concrete carries aggressive elements harmful to concrete such as sulfates or to its embedded reinforcing steel bars, such as carbon and chloride ions.

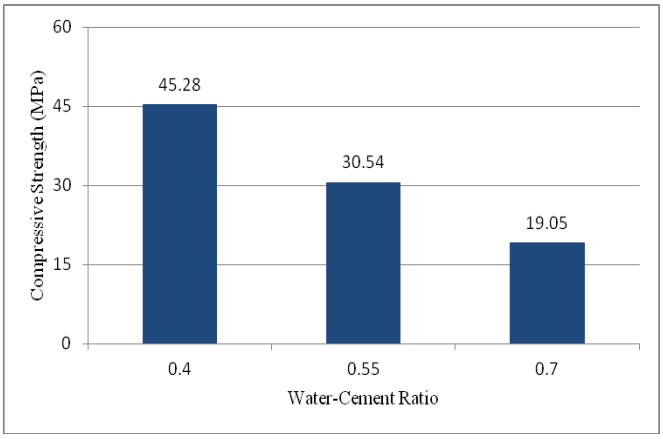

Figure 3. Effect of Water-Cement Ratio on Compressive Strength of Concrete After 28 Days

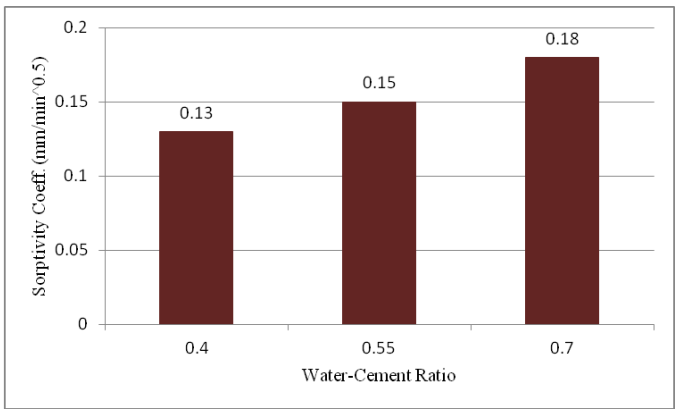

Figure 4. Effect of Water-Cement Ratio on sorptivity in Concrete

IV. Conclusion and Recommendations

In this paper, the effect of water-cement ratio on strength and durability parameters of hardened concrete was investigated experimentally under laboratory conditions. Three types of concretes with w/c ratio of 0.40, 0.55 and 0.70 were used taking into consideration the relationship between their slump, compressive strength and rate of capillary moisture absorption.

It was found out that using more water for a certain amount of cement, or using less cement for a certain quantity of water (which defines the water-cement ratio) has detrimental effect to both strength and durability of concrete.

While the said practice results to convenience in manual mixing and ease in depositing concrete into forms, the overall effect is, obviously, harmful to the concrete structures because it increases the slump of concrete which most of the times results to bleeding of fresh concrete in forms and honeycombing in hardened concrete. It also lessens its compressive strength concrete which will result to lesser carrying capacity of structure and will ultimately lead to its failure even at normal loads. Finally, it was also found out that using more mixing water aided in greater absorption capacity in hardened concrete. This allows easy entry of external more external water which will result to early deterioration of the structure when the absorbed water caries species harmful to both concrete and steel bars.

It is hereby recommended that parallel studies be conducted using additives to concrete, such as fly ash, rice hull ash, saw-mill ash and some waste products derived from coconuts. Also, the inclusion of other durability parameters such as chloride ion ingress from seawater and time-to-initiate corrosion using the abovementioned products are hereby recommended.

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