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Generating water/binder ratio -to- strength curves for cement mortar used in Masnory walls

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HIGHLIGHTS

- A wide variety of wastes available and encourage to be encountered inside the construction industry.
- The mineral admixtures such as silica fume, fly ash and granular blast furnace slag etc. were widely investigated.
- An optimum of 15% cement replacement was deduced to enhance the hardened state of concrete with water –to- binder ratio of 0.35.
- The validity of Abram's law presenting the relation between water-to-cement ratio and the compressive strength of concrete as well as cement mortar were extensively studied and ensure estimating the compressive strength at 7, 28 till 365 days.
- Empirical equations are developed to predict the strength of cement mortar for different water-to-binder ratio and different binder-to-fine aggregate ratio.

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ABSTRACT

In this paper, influence water/binder ratio on the hardened state properties of cement mortar was investigated after 28 days curing period as assigned by ACI Standard. From the results, empirical equations have been generated evaluating the strength of cement mortar mixes with various water/binder (w/b) ratios. It was deduced that Abram's law is valid most of cement mortars established. The cement mortar consists of ordinary Portland cement with 15% partially replacement by silica fume, fine aggregate (sand) with varying portions of 1:3, 1:4, 1:5, 1:6 and different water binder ratios ranged from 0.4 to 0.8. From results, a relationship between split tensile strength and compressive strength of cement mortar has been reached. Furthermore, it was observed, from the results; that a reduction in compressive and tensile strength of cement mortar, while, increasing the water-to-binder ratio higher than 0.5 in case of cement: sand of 1:3. While, this effect was deduced at water-to binder ratio of 0.7 when using cement: sand of 1:4, 1:5, and 1:6. It is concluded that the optimized water-to-binder ratio required for achieving workable cement mortar was mainly based on cement: sand portions. Moreover, empirical equations were generated to predict the relevant compressive and tensile strength to the w/b ratio and cement: sand ratio for practical. The predicted values revealed a good agreement with the experimental results observed.

1. Introduction

Growth of developing countries rely mostly on the energy. The demand to save energies consumed by materials manufacturer such as those of steel and cement etc. increases by indigence inquiry to reduce these non-reversible energy. In this sense, the world trend have in sighted the importance of recycling the industrial wastes for use in construction field. Cumulative large amount of by products and/or industrial wastes lost without any use each year [31]. But still the efficiency of using these wastes is in question. Tough, the natural resources will be saved and influenced sustainability. For instance, concrete industry encouraged the use of mineral admixtures which are By-products of other industries. Thus, in today's concrete manufacture, the introduction of industrial by product reduces the negative impact initiated by concrete on environment.

One of these materials is the silica fume consisting of silicon or ferrosilicon alloys resulted from amorphous form of silicon tetrachloride combusted by hydrogen-oxygen flame [30]. Several researchers [29,11,34,10,32,24,12,7] investigated the use of the silica fume in concrete mix and discovered their enhancement to the

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concrete properties. Binding materials play an important role in the quality, durability and strength of the cement mortar.

Yogendran et al. [35] investigated the addition of silica fume through experimental program. The design of mixes assigned, in this experimental program; to maintain high strength concrete. The authors observed a high increase in compressive strength and significant reduction in slump even though with the addition of super plasticizer by approximately 0.75% on average. On the other hand, Hootan [13] has investigated both physical and durability properties such as cyclic freezing and thawing, sulphate attack and alkaline silica reactivity; when silica fume partially replaced cement in a concrete mix. It was deduced that 28 days compressive strength was maximized when replacing 15% of cement with silica fume. It should be mentioned that author added variable dosage of superplasticizer as water – to – binder ration equal 0.35.

Shreekedar and Kumbhar [36] have studied the mineral admixture and its influence by high performance concrete. They replaced cement with micro silica adding super plasticizer to the mix for more workability. They observed that better strengths were achieved at 15% replacement. Recently, Hunchate et al. [14] have investigated the high performance concrete by using mineral admixtures such as silica fume. The study included several percentage of replacement; 0, 5, 10, 15, 20, and 25%. The water-to-binder ratio considered was equal to 0.29. It should be mentioned that the aging factor was considered as testing the cubes on both 7 and 28 days. From the results, they deduced that optimized percentage of replacing cement with silica fume is around 15%. Above this value, the reduction of compressive strength might be resulted. It was noted that as the silica fume replacement increases, the workability decreases. It should be noticed that few investigation studied the influence of cement: aggregate either coarse or fine or even both.

Historically, in concrete technology, Abram's formula was the first one describing the dependence of concrete strength on water-to-cement ratio [1]. In fact, Abrams suggested a formula that represents a relationship between concrete strength and water-to-cement ratio. The formula as seen generalized the inversely effect of water-to-cement ratio on compressive strength [25]. The formula Eq. (1) is as follow:

$$Strength = \frac{K_1}{K_2^{\frac{w}{c}}} \tag{1}$$

where K_1 and K_2 are constants, w represents mass of water and c assigned for the mass of cement. The validity of this formula was proven above water-to-cement ratio ranges from 0.3 to 1.20 for an average Portland cement concrete cured under normal temperature and moisture. Oluokun [8] had deduced using Abrams relationship between strength and water-to-cement ratio both constant coefficients K_1 and K_2 were evaluated through his investigation at different aging of 7 and 28 days. The following Eq. (2) presents the resultant of the estimated coefficient; K_1 and K_2:-

$$f_{c7} = \frac{63.45}{14^x} \quad and \quad f_{c28} = \frac{96.55}{8.2^x} \tag{2}$$

where f_{c7} and f_{c28} represent the strengths in MPa at 7 and 28 days, respectively, while, x represents the water-to-cement ratio. Rao [9] had suggested an empirical equation that can estimate the compressive and split tensile strength of mortar through determining the water – to – cement ratio. The equation was limited to water-to-cement ratio greater than 0.4 and mainly rely upon Abram's law. On the other hand, Yeh [15] have studied the aging influence on Abram' law. He encountered the validity of Abram's law at many different ages' ranges from 3 to 365 days. Generally Rao [9] had deduced that several other parameters affect the mechanical properties of the cement mortar such as water-to-cement ratio, cement-to-sand ratio, types of cement material and finally the aggregate characteristics.

Many studies [33,5,23,27,17,24,8] have investigated the addition of mineral admixtures into concrete mix. Though to consider the encountering of mineral admixtures while mix design; the water-to-cement ratio was replaced by water-to-binder ratio instead. Thus, the strength prediction becomes more accurate [16,8]. Consequently, the water-to-binder ratio was formulated Eq. (3) as following:

$$x = \frac{w}{c + kf + s} \tag{3}$$

where x assigned for water-to-binder ratio; w, c, and f represented water, cement and fly ash content; in addition, s donated for granulated blast furnace slag (GBFS), while, k symbolized an efficiency factor. Duff [1] suggested the development of power formula, to the Abram's laws which is originally related the water-to-cement ratio with compressive strength of concrete. The formula takes the following shape:

$$f_{c,t} = \frac{A_t}{B_t^x} = A_t * B_t^{-x} \tag{4}$$

where Eq. (4) is similar to that of Eq. (1) with subscript (t) indicating age at (t) days; usually 28 days. Yeh [15] generated a power formula for estimating compressive strength at any given age without collecting data at that age. This was developed by using parameter trend methods such as regression and four parameter optimizing methodology to identify this relationship.

Metwally [20] stated that the implementation of either Abram's formula or power formula to predict the concrete strength at any age requires collecting of huge data at that age, then developing a specific formula using the time factor (age function) as a function in specific age strength (usually – 28 day strength) to estimate the strength at a given age.

Although all these data upon formulating the relationship between water-to-cement ratio and compressive strength, it still not applicable when adding mineral admixtures. Many researchers [8,24,16,18,9,26,15,27,23,5,28,22,33,25,31] studied and investigated the optimum percentage of adding mineral admixtures, however, nearly no one formulated an empirical equation for specified percentage at specified age to determine the corresponding compressive and splitting tensile strength.

Thus, the objective of this paper is to determine the influence of water-to-binder ratio on the cement mortar's mechanical properties such as compressive and split tensile strength, while examining the validity of the Abram's law for cement mortar at specified percentage of replacement; 15% of silica fume. Furthermore, empirical equation are developed to predict the strength of cement mortar for different water-to-binder ratio as well as different binder-to-fine aggregate ratio.

2. Research significance

A wide variety of wastes available and encourage to be encountered inside the construction industry. The mineral admixtures such as silica fume, fly ash and granular blast furnace slag etc. were widely investigated. From the researchers' results [29,11,34,10,32,24,12,7], an optimum of 15% cement replacement was deduced to enhance the hardened state of concrete with water-to- binder ratio of 0.35. The validity of Abram's law presenting the relation between water-to-cement ratio and the compressive strength of concrete as well as cement mortar were extensively studied and ensure estimating the compressive strength at 7, 28 till 365 days. However, nearly no guidelines or