Effect of Cement Consumption Optimization on Durability and Mechanical properties of Concrete

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Abstract: various regulations have always discussed the mixing ratio in concrete mixtures. This study investigates the durability and compressive strength of the concrete samples with water/cement ratios of 0.41 and 0.44 and different cement contents varying from 300 to 400 kg.m^{-3}. Results showed that neither a constant water/cement ratio nor the reduction of cement content has an undesirable effect on compressive strength. Nonetheless, this even can enhance the concrete durability in some instances. Naturally, the decline of water/cement ratio affects the concrete efficiency but concrete slump can be kept at an acceptable level by addition of admixtures.

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Introduction:

Among the materials which are widely consumed by human being, Concrete takes the third place after water and food (krishnaswami, 2009). This is made by mixing the certain ratios of fine-grained and coarse-grained cement. The mixture becomes rock-hard when taking shape. As time passes, the chemical reactions between water and cement enhance the concrete strength. The strength, durability and other properties of concrete depend upon the property of components, ratio of materials, vibration method and other controlling methods which are used during mixture preservation and emptying process (NagabhuShana and sharada-bai, 2011; kett, 2010). Different variations in each of these factors can affect the quality of concrete. Therefore, the process of concrete mixtures optimization involves the specification of concrete composition so that the properties of fresh or hardened concrete are optimized (a certain property of concrete minimized or maximized) (Goderziam et al, Amir et al, 2012; Chris and Roozbe, 2009; Abdal-Aleam and Arumairay, 2012).

The combination of design methods in different countries, for example BS, USBR, and ACI standards of mixing plans, are generally based on the relations between the empirical tables and graphs gained from growing researches (Adegbola and Dada, 2012). All these instructions seek to reduce cement consumption by keeping water/cement ratio at a constant level (Behrouzi Khah et al, 2012).

According to the previous studies, the reduction of cement consumption at constant water/cement ratios has no side effect on concrete properties. Thus, this study aims to determine the optimum percentage of the cement consumed in concrete mixtures.

Since cement production process is a polluting industry, reduction of cement consumption and determination of its optimum percentage in mixtures not only lowers the costs but also may satisfy the environmental requirements. For instance, production of one ton of cement requires the consumption of two tons of raw materials and releases one ton of CO gas along with 180 kilograms of dust into the atmosphere. On this basis, the reduction of cement consumption has considerable impact upon pollutant reduction (Behrouzi Khah et al, 2012).

Numerous researches have been carried out on the effect of cement content on mixture's functional properties. Results show it is possible to reduce cement content of concrete mixtures and the properties of these mixtures are generally dependent upon water/cement ratio (Aleksander and Kapekco, 2006; Buenfeld and Okundi, 1998; Monterio and Helene, 1994).

Dhir et al found that for the concrete samples of various aggregates and cement types, the reduction of cement content at constant water/cement ratios had a small effect on mixture's adhesion, air percentage, and finishability, while debonding, water absorption percent, and water penetration percentage decrease. They also observed that the reduction of cement content has improved the functional properties of concrete such as compressive strength, flexural strength, elastic modulus, shrinkage, and creep strain (Dhir et al., 2006; Dhir et al., 2004; Dhir et al., 2000).

Methodology:

The aim of this study is to investigate the effect of cement content reduction at various water/cement ratios on the mechanical properties and durability of concrete mixtures. To achieve this, two water/cement ratios of 0.41 and 0.44 with the cement contents varying from 300 to 400 kg.m^{-3} for each ratio were chosen. Lignosulphonate plasticizers were sufficiently added to the mixtures with low cement content in order to compensate the effect of cement reduction on the prepared mixtures' workability so that the samples' slump was kept between 8 and 12 centimeters. Compressive strength and electrical resistivity tests were done to investigate the effect of cement content on mechanical properties and durability of prepared concretes. This study employed compressive strength test as an indicator of mixture's mechanical properties, while electrical resistivity and water absorption percentage tests were done to evaluate mixtures' durability. Portland cement type I was used for concrete mixture preparation. Tables 1 and 2 give the physical and chemical properties of the used cement.

Ground gravels of diameter between 4.75 and 16 millimeters and natural sand particles of diameter between 0 and 4.75 with the fineness modulus of 2.98 were used as the aggregates. Mixtures with water/cement ratios of 0.41 and 0.44 and cement contents varying from 300 to 400 kg.m^{-3} were prepared and used. The mixing ratios are listed in tables 3 and 4.

Table1. Physical properties of the used cement

Physical Tests	
Specific Area of Samples (Fineness) (kg/m^2)	290
Initial Setting Time (min)	145
Final Setting Time (min)	210
(MPa) 3-Day Compressive Strength	18
(MPa) 7-Day Compressive Strength	29
(MPa) 28-Day strength of 50-millimeter Cubical Samples	40
Volume Increase Percentage in Autoclave Test	0/2

Table 2. Chemical properties of the used cement

Chemical analysis	
SiO_2	20/03
Al_2O_3	4/53
Fe_2O_3	3/63
CaO	60/25
MgO	3/42
Na_2O	-
K_2O	-
SO_3	2/23
L.O.I	1/37

Table 3. Mixing ratios for water/cement ratio of 0.41

Sample Name	Cement Content (kg/m^3)	Water Content (kg/m^3)	Coarse aggregates weigth	Fine aggregates weight	Water Reducer Admixture
A	300	124	780	1150	3/7
B	325	134	770	1120	3/2
C	350	144	730	1120	3
D	375	155	730	1080	2/5
E	400	165	750	1040	2/3

Table 4. Mixing ratios for water/cement ratio of 0.44

Sample Name	Cement Content (kg/m^3)	Water Content (kg/m^3)	Coarse aggregates weigth	Fine aggregates weight	Water Reducer Admixture
A	300	134	770	1150	3/4
B	325	147	760	1120	3/2
C	350	154	730	1120	3
D	375	165	730	1080	2/4
E	400	175	750	1030	2/2

The samples were prepared in a mixer based on the ASTM C 192M: fine and coarse aggregates were mixed with water and plasticizer for three minutes. The prepared mixture was awaited in mixer for three minutes and then, the final mixing lasted for two more minutes. The prepared mixtures were poured into the molds and compressed. Two different molds with dimensions of 150×150×150 millimeters and 100×100×100 millimeters were used for compressive strength test samples and electrical resistivity test samples, respectively. The samples were kept in molds for one day in order to gain a preliminary strength. Then, samples were removed and saturated with water and finally, cured with calcium hydroxide at 22 °C. To measure the compressive strength of the mixtures, the 150-millimeter cubical samples were tested after 3, 7, and 28 days of preparation, based on the standard..

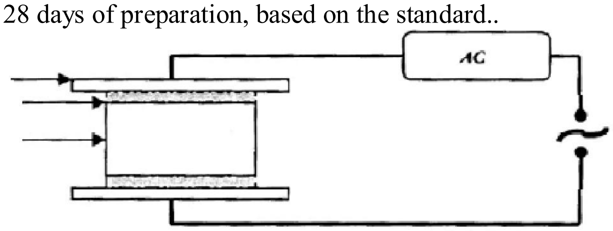

Figure 1. Sample's electrical resistivity measurement set-up

Results

The effect of cement content on the compressive strength of mixtures is shown for both water/cement ratios in figures 2 and 3. It is obvious that the increase of cement content has no considerable effect on the samples' compressive strength. This observation is valid for both water/cement ratios. Therefore, compressive strength is just a function of water/cement ratio and does not depend upon cement content of the mixtures.

An increase in cement use leads to an increase in cement paste content of the mixture. This paste must provide a good adhesion of aggregates. Thus cement consumption reduction is desirable to the extent that the required adhesion of aggregates is provided. The excessive increase of cement paste has no considerable effect on the samples' compressive strength since aggregate's strength is quite greater than cement paste's. Furthermore, an increase in cement content of mixture results in an increase of spontaneous shrinkage which will undesirably affect the mixture's strength. As it is obvious from the plots, the reduction of cement content from 400 to 325 kg.m^{-3} impose just trivial variations on mixtures' strength but as cement content decreases from 325 to 300 kg.m^{-3}, a sudden reduction of the mixtures' compressive strength is observed which may be caused by the reduction of aggregates adhesion.

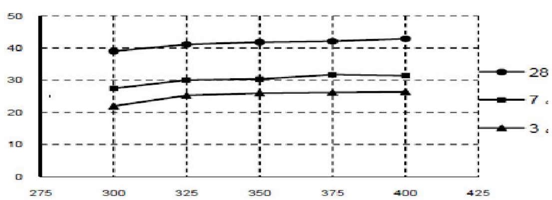

Figure 2. Compressive strength of samples at water/cement ratio of 0.41

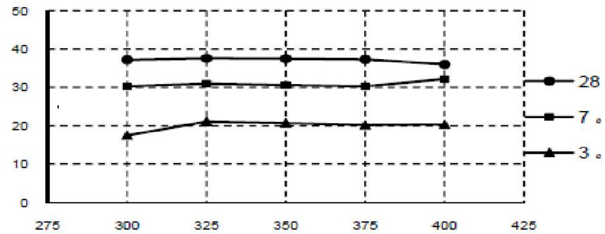

Figure 3. Compressive strength of samples at water/cement ratio of 0.44

Figures 4 and 5 show the variations of mixtures' electrical resistivity with respect to their cement content at the similar water/cement ratios. Figures demonstrate that the mixtures' electrical resistivity slightly increases by reduction of cement content from 400 to 325 kg.m^{-3} and then, starts to gradually decreases as cement content further decreases from 325 to 300 kg.m^{-3}. The reduction in cement content of mixtures leads to a decrease of mixtures' cement paste which is the main path of electrical current flow. The electrical conductivity of aggregates is quite less than that of cement paste and since the aggregate contents of all samples are the same, aggregates have no effect on the results. In addition, if cement paste falls below a certain level, the porosity of mixture increases and, as a result, the mixture's electrical resistivity decreases. The mixture's electrical resistivity is an indicator of its durability, thus it is observed that the reduction of cement content to 325 kg.m^{-3} can improve the mixtures' durability. This finding is in accordance with the previous observation of cement paste adhesion reduction below the cement content of 325 kg.m^{-3}.

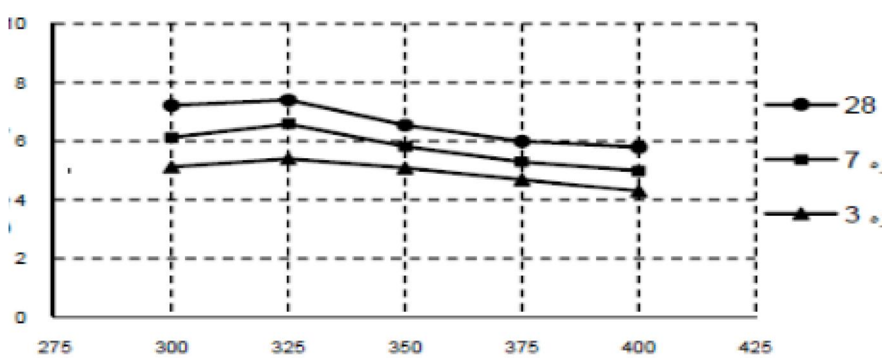

Figure 4. Electrical resistivity of samples at water/cement ratio of 0.41

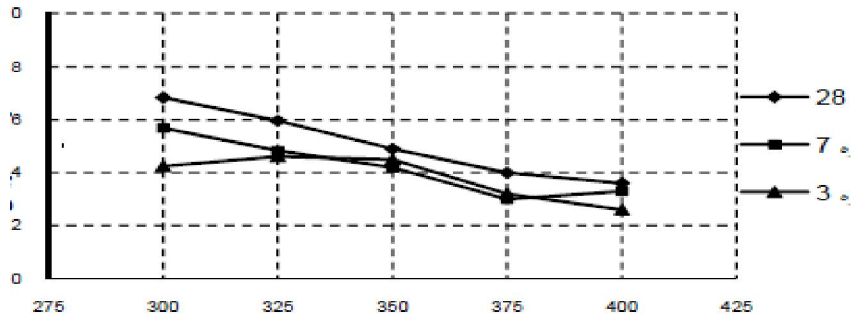

Figure 5. Electrical resistivity of samples at water/cement ratio of 0.44

Conclusion:

The results obtained from mixtures' durability and strength tests are listed as follows:

- Compressive strength of the prepared mixtures showed no considerable variation with respect to cement content variation. Therefore, it is concluded that the compressive strength of the mixtures does not depend on cement content and is just a function of water/cement ratio.
- Electrical resistivity of the mixtures slightly increases as cement content decreases at constant water/cement ratios.
- Considering the fact that compressive strength is scale of concrete's strength properties evaluation and electrical resistivity can serve as a scale of concrete's durability evaluation, it can be concluded that it is possible to reduce the cement consumption by 20% (from 400 to 325 $kg.m^{-3}$) without losing the strength and durability of concrete.
- The reduction of concrete quality for the cement contents below 325 $kg.m^{-3}$ may be caused by the decrease of aggregates adhesion to each other. This can further be investigated in upcoming researches.

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