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# Influence of Fly Ash and Dense Packing Method to Increase Durability of HPC Subjected to Acid Corrosion

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## ABSTRACT

In recent years, progress in science and technology in the field of concrete and usage of different materials, along with advanced and innovative techniques, has resulted in the use of reinforced concrete in special structures including cooling towers of power plants, sewage system and structures that have increased remarkably in aggressive conditions or chemical attack. In this article, a method for producing a kind of high performance concrete has been introduced that brings about an increase in the durability and a decrease in the permeability of concrete, as well as a reduction in the amount of cement content, by approximately 40 %. In this regard, in order to study the function of durability of such concrete, examinations have been conducted, such as compressive strength, determination of permeability depth under water pressure, chloride ion permeability, expansion against sulfates and resistance against sulfuric acid.

## INTRODUCTION

Today with the increasing use of concrete, the expectation for the appropriate functions of this material has increased. The extent of concrete application is great, such that it is used in buildings, bridges, dams, sewer pipes, cooling towers, and industrial floorings. In such applications the durability of the concrete exposed to chemicals and especially to acids, is of specific importance. Sulfuric acid may be present in underground water, sewage, wastewater from industrial plants, or from the oxidation of sulfur containing material (such as pyrite) [Fattuhl and Hughes, 1988; Hobbs and Taylor, 2000; Bassuoni and Nehdi, 2007]. The majority of the decay from acid attack is seen in the concrete elements applied in some factories, pipes and parts used in sewer systems [Bassuoni and Nehdi, 2007]. However, the research and study of corrosion due to the sulfuric acid attack has a long history [Fattuhl and Hughes, 1988], but still a great number of the researchers around the world are looking for ways to increase concrete life in such situations.

In general, there are two methods to increase the durability of the concrete against acid corrosion [Bassuoni and Nehdi, 2007; Daczko et. al., 1997]:

- Use of different material and substances, improvement of the concrete mix ratio in order to increase its chemical strength
- Reduce the production of sulfuric acid by bacteria

Based on the knowledge of concrete technology, its durability against corrosion resulting from sulfuric acid can be improved by reducing the water to cement ratio, reducing the cement content, use of mineral or polymer additives, cement type and use of calcareous aggregates [Fattuhl and Hughes, 1988; Hobbs and Taylor, 2000; Bassuoni and Nehdi, 2007].

Numerous studies have observed the effect of one or several limited parameters for increasing the chemical resistance of concrete. The current research aims to observe the durability of a type of concrete in which the cement content is reduced to the lowest amount possible by using the *Dense Packing* method, in addition to the use of *ternary binder* adhesive material system to increase the durability.

## DESIGN PRINCIPLES

Corrosion due to sulfuric acid is a deterioration that starts from the concrete surface and gradually results in the decay of a whole concrete element, hence two general solutions may be considered. 1- Reducing the concrete permeability, and 2-Increasing the resistance of the parts susceptible to acid.

In order to reach the first factor, various solutions considered for high performance concretes are usable. For this manner, reducing the water to cementitious material ratio, using cement substituting material and in most cases increasing the content of the cementitious material are common. However, the parts of concrete susceptible to acid attack may be divided into two phases. The first phase concerns the aggregates and the second phase concerns the paste. Almost all researchers agree on the point that reducing the volume of the paste may be one of the suitable solutions. Others believe that the use of limestone based aggregates due to the buffering effect and decrease in acid concentration are effective. Since the vulnerability of the paste decreases and in other words the paste and aggregates are subject to about the same amount of decay where using acid resistant aggregates will cause the deterioration to only affect the paste and defect in this area will be greater.

Although, each of the mentioned methods above may be effective, however since they affect the other properties of the concrete, they are not recommended as a definite solution. In this paper the application of a type of high performance concrete using the *dense packing* method to reduce the paste in addition to using two cement substituting materials (pozzolanic) while increasing the density and decreasing the porosity, has been studied. Although using ideal curves such as the Fuller curve has an old background but to due some limitations, including decline in workability and possibility of segregation, its application has become limited. In this research by modifying the Fuller and Thompson relation, using the curve while saving the workability of the concrete allows the above mentioned items to be achieved as well.

In Figure 1, an example of the Fuller and modified Fuller and Thompson grading curves is shown. As seen, in the coarse and fine grain fractions, these two curves have differences. The Fuller curve has greater values in the region of coarse aggregates but in the part of fine aggregates (0.01-2mm) the values are less. The modification has caused the concretes made based on this relation to have a better workability and consistency and have better packing in practice.

Generally, the use of the curve has the following advantages:

1- Greater compaction of such concretes in comparison to similar high performance and traditional concretes
2- Greater compressive strength in comparison to similar high performance and traditional concretes with the same cement content
3- Use of fines matter as filler
4- More water retention than concrete
5- Calculating the amount of aggregates and cement material based on the cumulative percentage from the curve

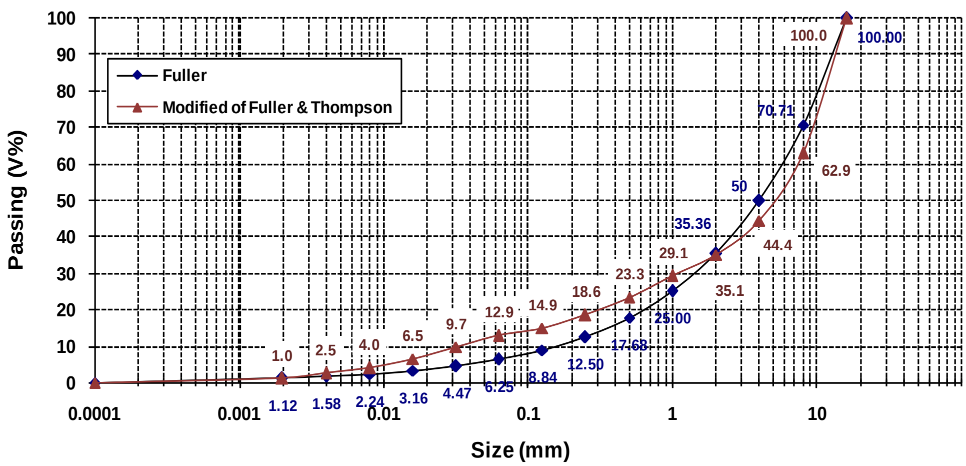


Fig. 1. Fuller and modified Fuller and Thompson grading curves

## EXPERIMENTAL STUDIES

### Substances and materials

In this research two types of cement substituting material (silica fume and fly ash) along with Portland cement type II (according to ASTM standard) have been used. For choosing the type and mix percentage of the adhesive material, two factors were considered: 1) chemical composition and 2) grading. Table 1 and Figure 2; present the chemical analysis and grading curves. In order to reach the dense packing in the fines (grains smaller than 63 microns) it was necessary to use proper filler. The filler used was quart with a grading as shown in Figure 2.

The ratio of adhesive material including cement, fly ash and silica fume was chosen as 70, 20, and 10, respectively [Parhizkar, et al., 2007].

The aggregates used were siliceous and resistant to acid attack and grading of the combination is shown in Figure 3. The density is 2.62 $g/cm^3$ and the water absorption in SSD state was 2.65%.

The super-plasticizer consumed was carboxylate commercially named structure 335 and the amount consumed was according to the manufacturer's guidance and to achieve the suitable consistency and workability.

Table 1. Cement and micro silica chemical analysis

| Chemical composition (%) | Cement | Micro silica | Chemical composition (%) | Cement | Micro silica | Chemical composition (%) | Cement |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | 20.96 | 95.1 | MgO | 3.4 | 0.6 | $C_3S$ | 52.74 |
| $AL_2O_3$ | 4.2 | 0.6 | CaO | 61.88 | 1.02 | $C_2S$ | 20.31 |
| $Fe_2O_3$ | 4.6 | 1.1 | $SO_3$ | 1.79 | 1.2 | $C_3A$ | 3.35 |
| | | | | | | $Na_2o$+O.658$K_2O$ | 1.47 |

**Mix proportions**

As previously mentioned, in order to determine the mix ratio the philosophy of achieving maximum packing by applying the modified Fuller and Thompson (F&T) relation was used [Parhizkar, et al., 2007]. In this method the mix percentage of solid matter is chosen such that it is closest to the ideal curve. Figure 1 shows the modified F&T grading curve. As shown, when the maximum grain size is 16mm, the percent passing of the 63 micron sieve (as the border between powders and aggregates) is 12.9 % (by volume). Based on this fact, the ratio of aggregate mixture was prepared to fall on the upper part of the curve (greater than 63 microns) and the percent mixture of an adhesive matter and filler such that it falls on part of the curve. As shown in Figure 3, the curve of the consumed material in the AC-R1 mix design falls suitably on the modified F&T curve, resulting in the maximum compression, but the other two mixes do not have the required match.

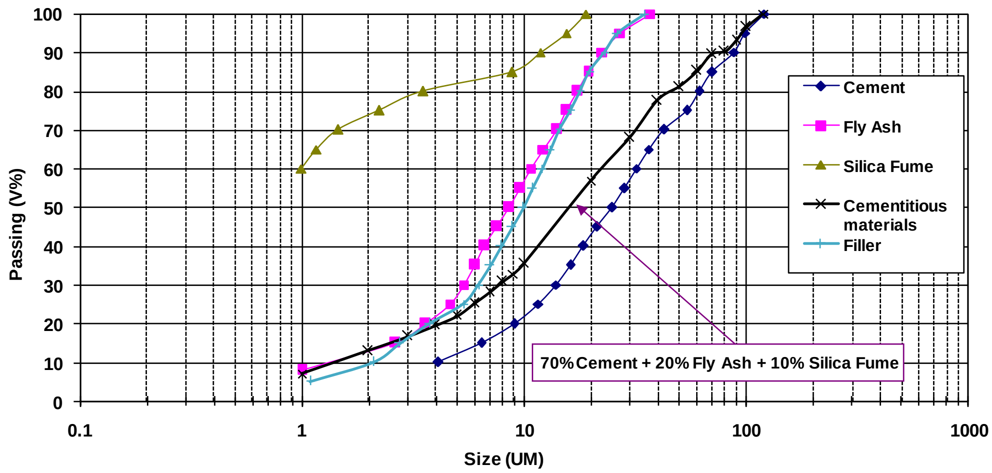


Fig. 2. Grading curves of cement, fly ash, silica fume, filler and cementitious materials

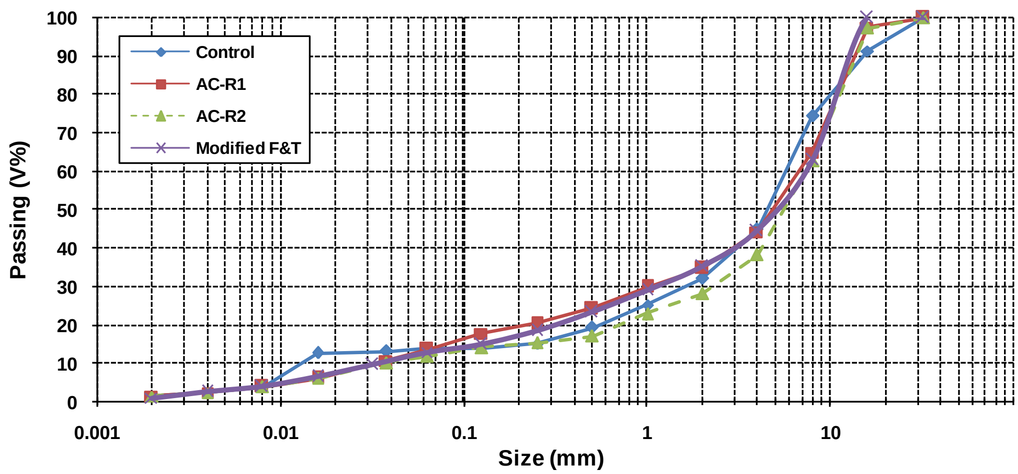


Fig. 3. Mixes combined materials curves and modified F&T curve

In order to increase the durability and decrease the porosity in the AC-R1 design, the water to cementitious material ratio was considered 0.396. In the AC-R2 design, the components mixture ratio was similar to the AC-R1 design (for purposes of comparison), except that fly ash was not used. Also, another design was prepared as a control mechanism. This design was built based on the relations existing for determining the mix ratio for high performance concrete, and was examined for the effect of using dense packing principles, comparing it to the designs resistant to acid. Table 2, presents the concrete component mix ratio in the examined designs.

Table 2. Mixing ratio of concrete components in different designs

| Mix index | Cement | Fly ash | Silica fume | Water-cement ratio | Aggregate (0-16) mm | Filler aggregate (0-0/25) mm | Super plasticizer |
|---|---|---|---|---|---|---|---|
| $Kg/m^3$ | $Kg/m^3$ | $Kg/m^3$ | $Kg/m^3$ | | $Kg/m^3$ | $Kg/m^3$ | (% cement weight) |
| AC-R1 | 245 | 70 | 35 | 0.4 | 1869 | 138 | 0.6 |
| AC-R2 | 220 | 63 | 31.5 | 0.4 | 2015 | 0 | 0.64 |
| Control | 315 | 0 | 35 | 0.4 | 1869 | 138 | 0.6 |

**Mixing procedure**

After modifying the moisture in the aggregates, each of components of the concrete are weighed separately and then, first the aggregates and afterwards the cementitious materials, water and lastly the super-plasticizer additive are poured into the mix and a pan mixer is used to do the mixing. The nominal capacity of the mixer is 250 liters and the blades rotate vertically and move in the opposite direction of the drum.

**Preparation and curing of the test specimens**

After weighing and mixing concrete components, concrete test specimens are produced and maintained. The concrete is placed in the molds according to EN standard 12390-2:2000. After keeping the test specimens in standard conditions (moist room) for one day, they are removed from the molds and transferred to the curing basin with a temperature of 23°C and are kept there until the test time.

**Fresh concrete tests**

In order to determine the characteristics of fresh concrete, weight determination, percent air content, consistency with slump method, and temperature determination tests were performed. The results of these tests are presented in Table 3.

Table 3. Fresh concrete test results

| Mix index | Concrete temperature | Slump | Unit weight | Entrapped air |
|---|---|---|---|---|
| | (degree) | (Cm) | ($Kg/m^3$) | (%) |
| SN | 21 | 4 | 2391 | 3.8 |
| FSN | 22 | 0 | 2466 | 2.0 |
| FSPD | 25 | 12 | 2505 | 1.0 |
| SPD | 21 | 10 | 2533 | 1.5 |

### Test results for hardened concrete

*Compressive strength*

In order to determine the compressive strength and study its increase process for the concrete in this research, 100 mm cubic test specimens were provided. The test specimens were examined in 7, 28 and 90 days (3 test specimens for each age). The compressive strength of the test specimens were measured according to EN 12390-3:2000 standard and the results of the test are presented in Figure 4.

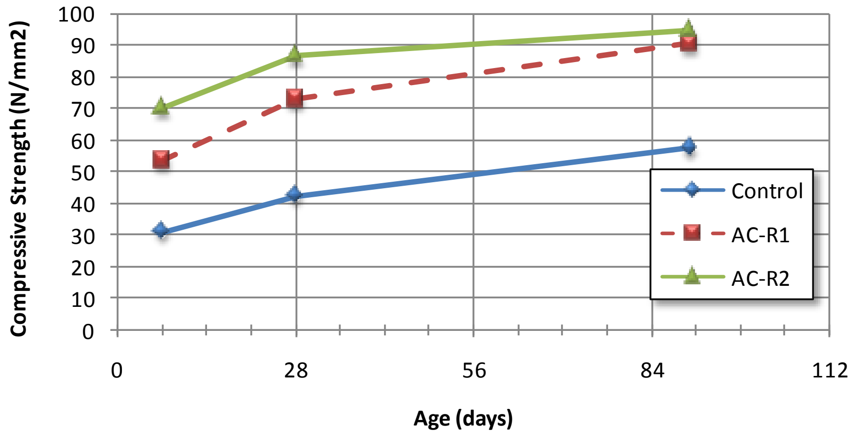


Fig. 4. Compressive strength test results

*Rapid chloride penetration test*

Improving the concrete penetration parameters has a considerable effect on increasing its durability. The Rapid Chloride Penetration Test (RCPT) is appropriate for designing and examining useful life (servicing) of concrete against chloride ion. This test is performed according to ASTM C 1202-97 standard on cylinder test specimens with 100 mm diameter and thickness of 50 mm that in this research were performed by using cylindrical test specimens 200×100 and with standard cutting for 28 and 90 days.  Results are presented in Figure 5.

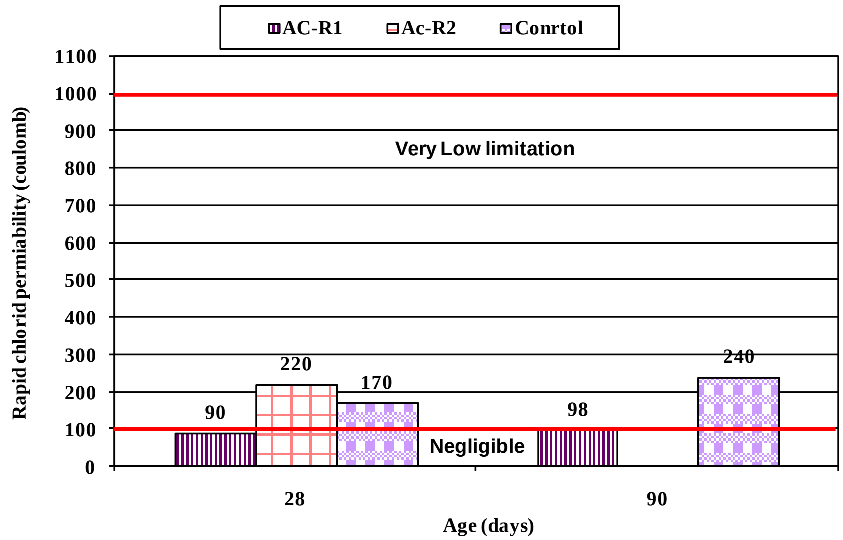


Fig. 5. Rapid chloride penetration test results

*Determination of water penetration depth under compression*

One of the most important effective parameters on increasing concrete durability against aggressive agents (which penetrate from the environment) is decreasing concrete penetration. This test was performed according to EN 12390-8:2000 standard on cubic test specimens 150 mm long for 28 and 90 days. The results are shown in Table 4.

Table 4. Water penetration depth test results

| Mix index | Water penetration depth(mm) | |
|---|---|---|
| | 28 days | 90 days |
| FSPD | 0 | 2 |
| FSN | 10 | 24 |
| SPD | 4 | 5 |

*Weight loss in exposure to sulfuric acid*

For this purpose a basin and pH control and regulating system was designed and built. This device consists of the following general parts:

- acid tank
- storage tank
- tanks for keeping the specimens
- pH control and order system

In the acid tank, diluted sulfuric acid is kept so that in case of pH drop, the acid enters the storage tank in the amount needed by the order of the control device.

Using a special pump between the storage tank and the tank holding the samples, the acid solution is in constant circulation. The controlling system keeps the pH of the solution constant, (between 1 to 2), and when necessary by sending a command to the electrical valve allows the sulfuric acid to enter the storage tank.

The concrete samples are kept under laboratory conditions after 28 days of treatment in standard conditions until the age of 56 days in the lab environment and then are transferred to the above mentioned device. At equal time intervals, (about once a month), the samples were removed from the tank and weighed after brushing and cleaning of the surface. The results for the percent weight loss of the samples are shown in Figure 6.

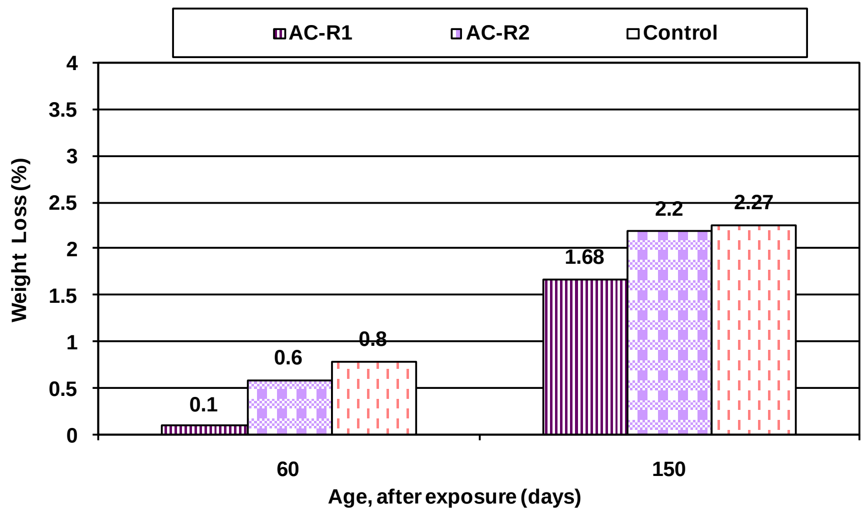


Fig. 6. Weight loss results of mixes in sulfuric acid, after 60 and 150 days exposure

## CONCLUSIONS

Three concrete designs were observed in this article. The AC-R1 mix was introduced as the new generation of high performance concretes in which two type pozzolans were applied to decrease the cement content and to make the paste durable against acid attack in addition to applying the dense packing method, the porosity and penetration of the concrete were decreased to the least possible. The total amount of cement material used was less than other traditional high performance concretes. The AC-R2 mix is a similar method to AC-R1 mix for which only silica fume was used as a substitute for cement in order to control and to observe the effect of fly ash. The control design did not involve the use of the dense packing method, in other words, the grading curve was different from the AC-R1 mix and filler was not used.

The AC-R1 mix, due to durability specifications, has the least water penetration, least percent passing (most resistance to penetration of chloride ion) and least weight loss against sulfuric acid attack.

1- Although the AC-R2 mix has greater compression strength than the AC-R1mix, as far as functioning against water and chloride penetration and weight loss in acid; it has less durability compared to the AC-R1 mix.
2- The control design based on the mechanical properties and durability is a lot weaker than the AC-R1 and AC-R2 mixes and cannot have suitable functioning in comparison to these two designs.

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