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Concretes with High Fly Ash Content

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ABSTRACT

The goal of this study is to study the strength and performance of concretes with high fly ash content, which consists in replacing 50% or more of the Portland cement needed with fly ash. Four concrete mixes with different Portland cement (C) and fly ash type F (FA) proportions are designed for each batch. In total, seven batches are prepared. The percentages of cement and fly ash for each batch are 100% C-0% FA (control group), 50% C-50% FA, 40% C-60% FA, and 30% C-70% FA. Between batches, the main difference is the water/cement ratio, or its total water content.

Results show that concretes with high fly ash content have lower initial strength, but along the time, the strength rises faster than the control group's mix. Also, concretes with high fly ash content need less water than normal concretes. Altogether, the high fly ash content greatly improves concrete's workability. Data from thermocouples indicate that concretes with high fly ash content release much less heat than the control group during the hydration process.

The effect of high fly ash content on the concrete's tension strength is also studied, observing that concretes with high fly ash content show lower ratio of tensile stress versus the square root of the compression strength than the control group. Finally, it is observed that concretes with high fly ash content produce more dust during abrasion of the exposed concrete surface than the control group, yet it trends stabilize with continuous abrasion.

Keywords: Concrete, fly ash, high content, strength

1. INTRODUCTION

Concrete has many different characteristics that have made it the most reliable and most convenient construction material among all mankind. Concrete's uniqueness, such as its exceptional resistance to water, excellent molding properties, low cost, compressive strength, and availability; are characteristics that have made this building material responsible for the construction of dams, highways, bridges, buildings, and many other major structures.

Concrete is obtained by mixing coarse aggregates, fine aggregates, water, additives, and cementitious materials, such as Portland cement or fly ash, which are the glue that makes all components bond and harden. Although Portland hydraulic cement is the primary element in the concrete production, it represents a significant problem to the environment, contributing to the green house phenomenon. For every ton of cement manufactured, about 6.5 million BTUs of energy are consumed, and about one ton of carbon dioxide is released into the environment (Headwater Resources, 2006).

Fly ash is a finely divided residue resulting from the combustion of ground or powdered coal. It is generally finer than cement and consists mainly of glassy-spherical particles as well as residues of hematite and magnetite, char, and others. The fly ash particles have different density. The type of fly ash used in this study is class F. Fly ash reacts with calcium hydroxide for cement hydration at ordinary temperatures, forming compounds with high cementitious qualities. It also reacts chemically with lime that is given off during cement hydration.

By replacing cement with fly ash type F, we are reducing the amount of cement needed, and consequently the amount of cement produced. Cement's production represents about seven percent of all carbon dioxide being generated by human sources. Fly ash is a byproduct from power plants that burn coal to generate electricity. However, these ashes cannot be simply thrown away, so using them in concrete helps remediate its disposal cost and benefits the environment.

Fly ash has many other benefits that make it a very efficient replacement for cement. Fly ash's spherical particles reduce the friction among the particles, allowing higher mobility and consistency in the concrete. This also means that less water is needed for the mix, and as a result, the segregation of aggregates is better controlled. Fly ash improves workability, makes pumping of concrete easier and extends pumping distances. Furthermore, it reduces the heat released by hydration which can ultimate prevent internal cracks that can be caused by the high temperatures given off by this exothermic reaction. Additionally, fly ash is significantly cheaper than cement. Moreover, fly ash type F, with particles covered in a kind of melted glass, greatly reduces the risk of expansion due to sulfate attack, as may occur near coastal areas (ToolBase Services, 2006)

People need to be educated about Fly Ash because of its great benefits. In India, the government is currently encouraging companies to utilize fly ash products, such as bricks, in at least 30 percent of their constructions. ''Blending fly ash with concrete can produce a more durable structure. This is because it makes concrete more dense, resistant to corrosion as well as more water-resistant,'' (Building Dreams, 2007).

2. DISCUSSION OF LABORATORY RESULTS

The experiment is conducted in the Structural Laboratory at the University of Houston Downtown. Seven concrete batches are made and tested over a period of seven months. Each of the batches is divided into four groups: 100% Cement (C)-0% Fly Ash type F (FA) (control group), 50% C-50% FA, 40% C-60% FA, and 30% C-70% FA. For each batch, all groups kept the same weight of cementitious material, water, gravel and sand. The variable between batches is the water to cementitious (w/c) ratio, or the total weight of water, but it kept the same for all groups in each batch.

The aggregates are obtained from the company Flexicore of Texas. Coarse aggregates used in this experiment have a maximum size of 3/8" with rounded shape. Sand or fine aggregate has a fineness modulus of 3.4. Other materials are type I Portland cement and a super plasticizer, which is a chemical admixture that is added to concrete mixtures to reduce friction among the particles, improving the workability. The control group is the only one that needs super plasticizer, since the high fly ash content mixes already have enough workability.

The concrete cylinders have a 3-in diameter by 6-in height dimensions. Twenty cylinders are poured for each mix design. The batch contains four groups with different mix design, obtaining 80 cylinders per batch. Seven batches are done, totalizing 560 cylinders during the study. For each group, eighteen cylinders are tested in compression, one under indirect tension, or Brazilian test, and another for monitoring the temperature during the hydration process. The compression test is performed on 2 cylinders every seven days, starting in the 7^{th} day-old. The indirect tension test is performed on one cylinder every seven days, starting the 28^{th} day-old. In some cases, the test is delayed to obtain the strength of an older cylinder. The results are plotted using a spreadsheet.

The compression test is done using a rigid frame and a hydraulic jack. The cylinder is capped with a rubber pad and a steel cap. Then, pressure is applied vertically with the jack until concrete fails. The maximum load is recorded and observations are made. The tension or Brazilian test is also done using a rigid frame and a hydraulic jack. The cylinder is padded with wooden strips at the top and bottom and laid on a side. Then, pressure is applied with the jack.

2.1 COMPRESSION TEST

After the compression test is performed, the maximum strength is recorded and plotted in a spreadsheet to visualize the increase in strength before, during and after they reached 28 days. Both, figures 1 and 2 show the strength in pounds per square inch (psi), fc, versus time in days, for the various mixes containing different percentages of fly ash and Portland cement. It can be appreciated that the strength of concretes with fly ash are lower than the control group, but they present a trend to gain strength with time. Also, it is noted that concretes with 5000 psi, or more, are obtained with high fly ash content, principally if the w/c ratio is lower than 0.35, the water content is 300 lb/cy, and the testing time is 40 days.

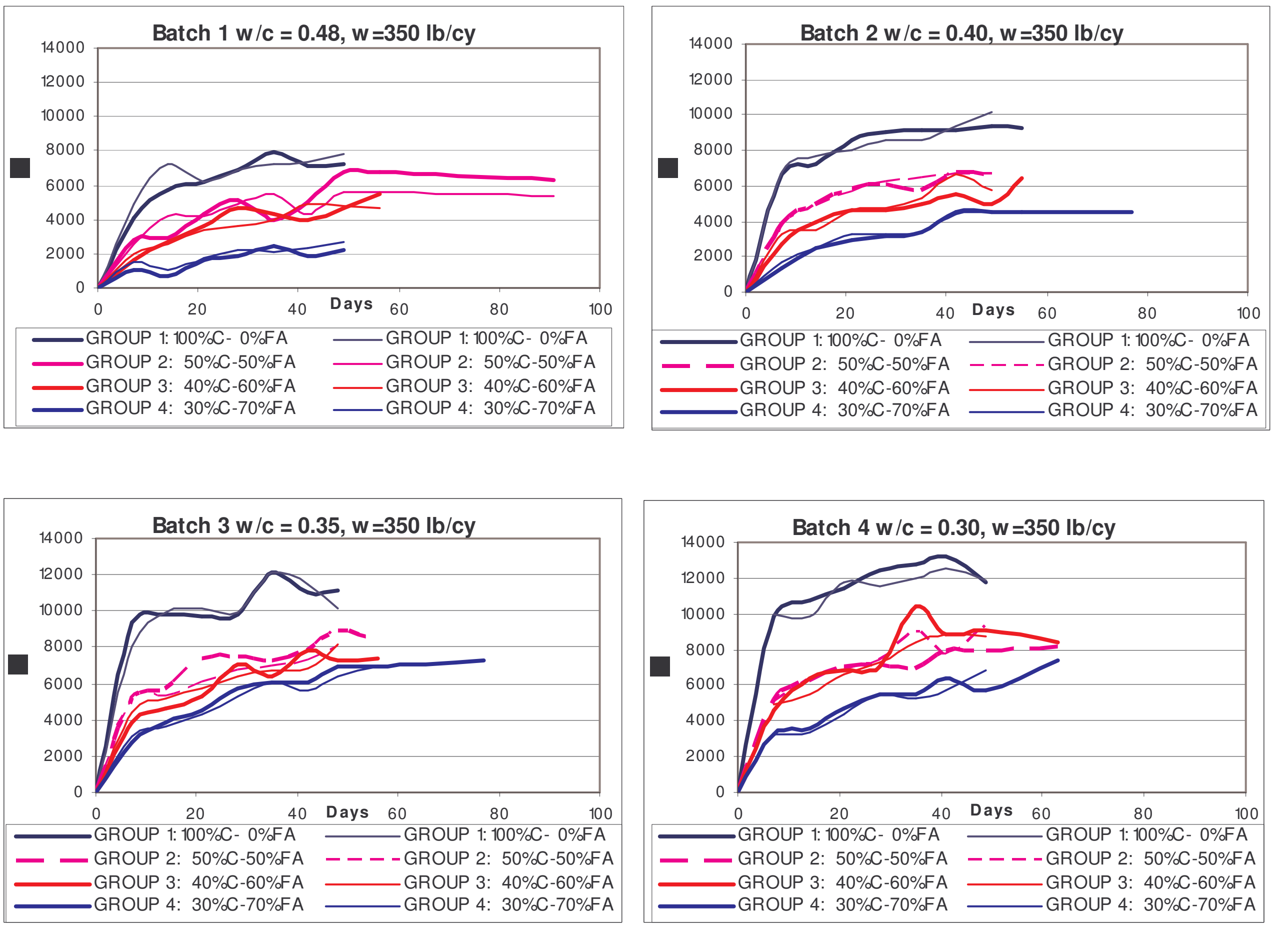


Figure 1: Compression strength versus time for concretes with different w/c ratio and a water content of 350 lb/cy.

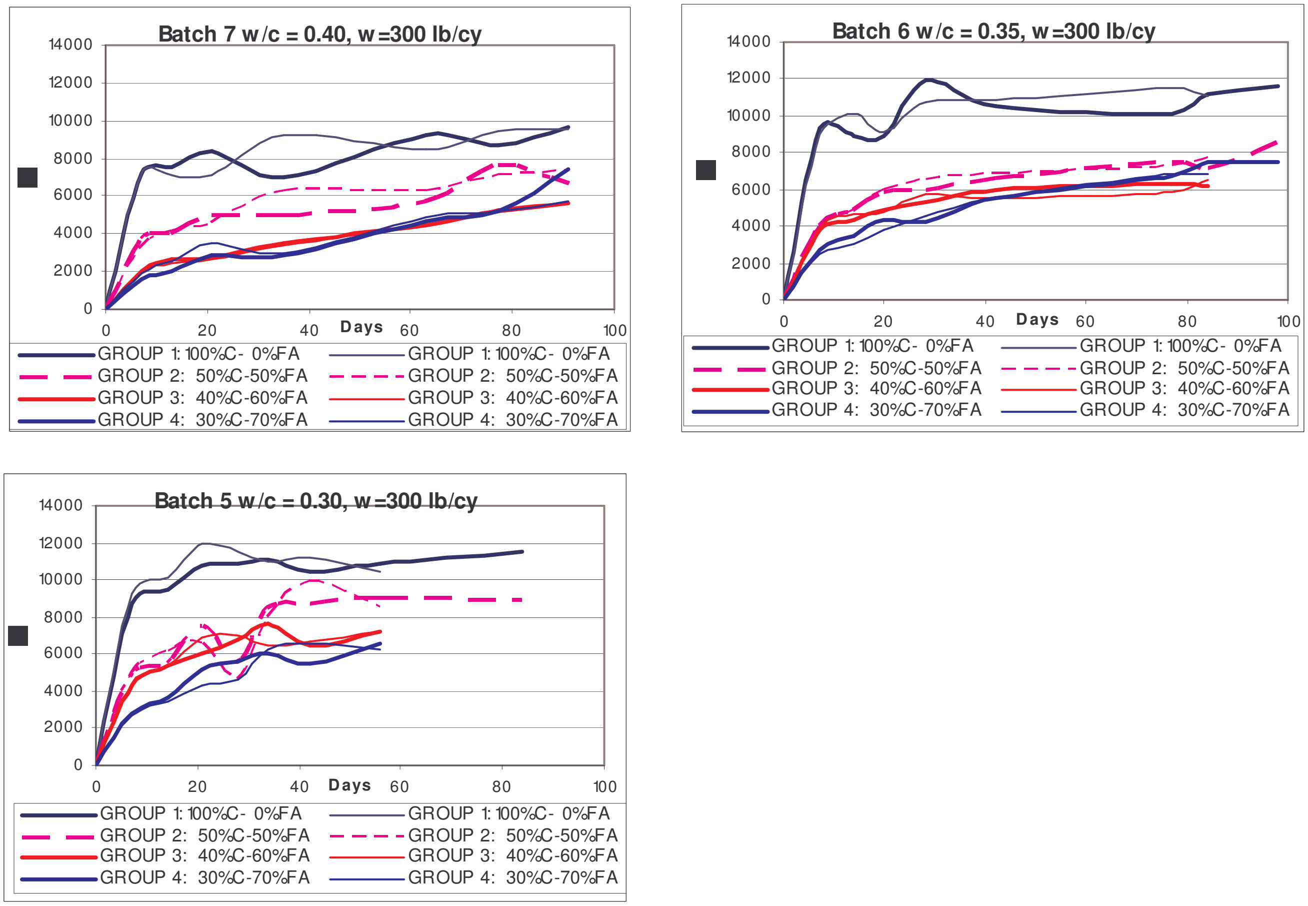


Figure 2: Compression strength versus time for concretes with different w/c ratio and a water content of 300 lb/cy.

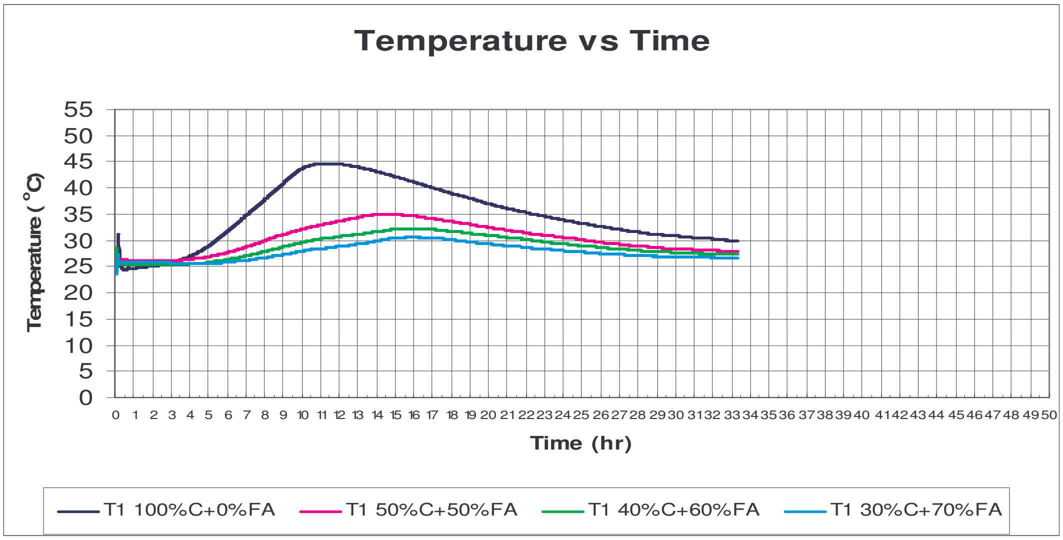
2.2 TEMPERATURE TEST DURING THE HYDRATION PROCESS

Hydration is the chemical reaction between a cementitious material and water that causes hardening of the mix. This reaction is exothermic which means that it releases heat. The temperature produced by this reaction is an important design parameter for massive concrete structures, because it has influence in the early cracks of the concrete.

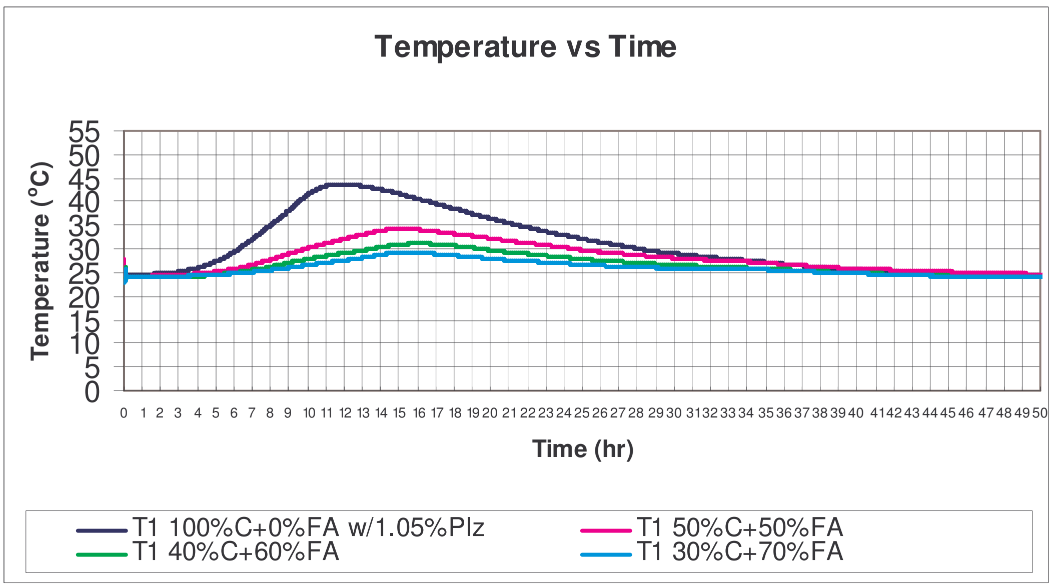
The temperature during the first 24 hours of hydration is measured for the different four groups. For this purpose, a wooden box of 1 cubic foot is constructed and filled with foam to insulate the concrete cylinder located in the center. The temperature is measured using a thermocouple attached to a data logger with four channels. The data obtained from this temperature test is shown in Figure 3.

The maximum temperature released during hydration for the control group is in the order of 45 ^{o}C, it reduces to 35 ^{o}C using 50% C-50% FA, 33 ^{o}C for 40% C-60% FA, and 30 ^{o}C for 30% C-70% FA. The shape and peaks of these curves are consistent from test to test, and also depends on the amount of the other components of the concrete.

It is observed that concretes with high fly ash content need more time for initial hardening, this may be important in extreme weathers and for certain works, like slabs or roofing. For example in summer it may help because there is more time to finish the surface, but in winter the waiting time to start the finishing may be too long.



Batch 1: September 9th, 2006



Batch 7: November 1st, 2006

Figure 3: Temperature released during hydration versus time

2.3 TENSILE STRENGTH

The results obtained from the indirect tensile strength, also known as splitting or Brazilian test, show that ratio of tension and the square root of the compression strength (ft / sqrt(f'c)) trends to reduce when high fly ash content is used, as shown in Figure 4. This graph shows the average of the tests performed to 122 cylinders aged 28 days or more. The data for the control group correlates with the statistical equation given by the Building Code ACI 318, which states that the ratio ft / sqrt(f'c) is 6.7 for Brazilian test (ACI, 2005). For the control group the average ft / sqrt(f'c) ratio obtained is 6.6. This average ratio becomes 6.3 for concretes with 50% C-50% FA, and 5.6 for concretes with 40% C-60% FA and 30% C-70% FA. However, more research is necessary to define a statistically correct correlation because the high dispersion of the results.

2.4 ABRASION

A qualitative abrasion test is also performed for concretes with different proportion of fly ash. A rectangular concrete plate 4-in wide and 12-in long, is constructed for each type of concrete from a specific batch. The plates are tested at their 126 days for dust released caused by abrasion. The abrasion effect is obtained by scraping the surface of the concrete slab with a wire brush using a normal force of roughly 15lbs. The released dust is weighted after 100 consecutive scrapes.

The results show that concrete from group 4, with the highest percentage of fly ash (70%), is releasing the highest amount of dust. However, the dust released trends stabilize when more scrapes are applied. Figure 5 represents the weighted dust released by the slabs versus the number of scraps. It is possible that the dust released is because some particles of fly ash have very low density. Further research is necessary for final conclusions.

The dusty surface shown in the upper face of the plates is not observed for the surface covered with the plastic form. In this case, after removing the plastic form of the cylinder it is appreciated a shiny and smooth surface.

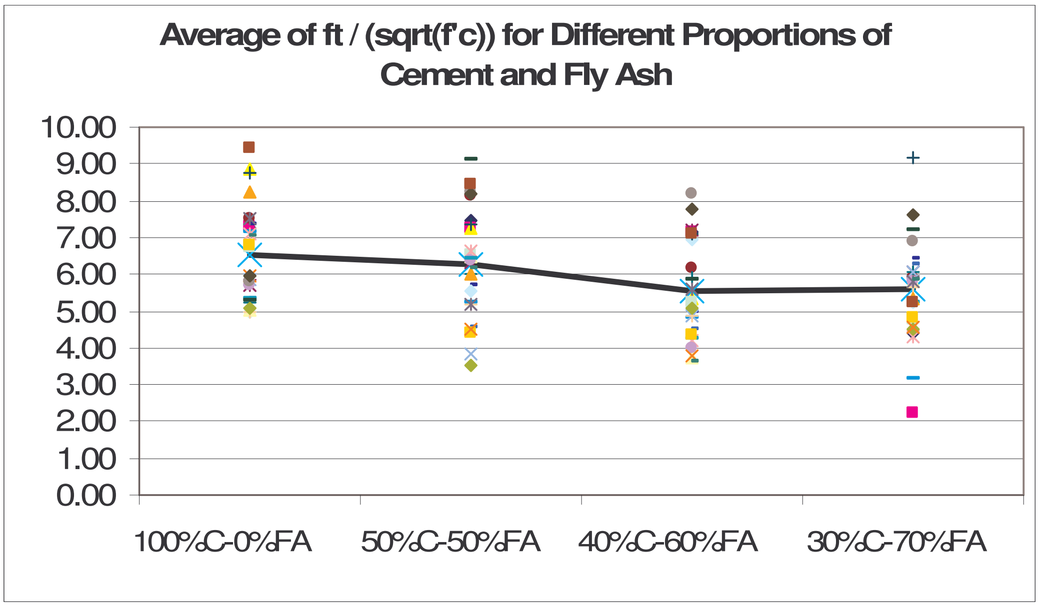


Figure 4: Variation of the ratio of tension and square root of compression strength with the fly ash content

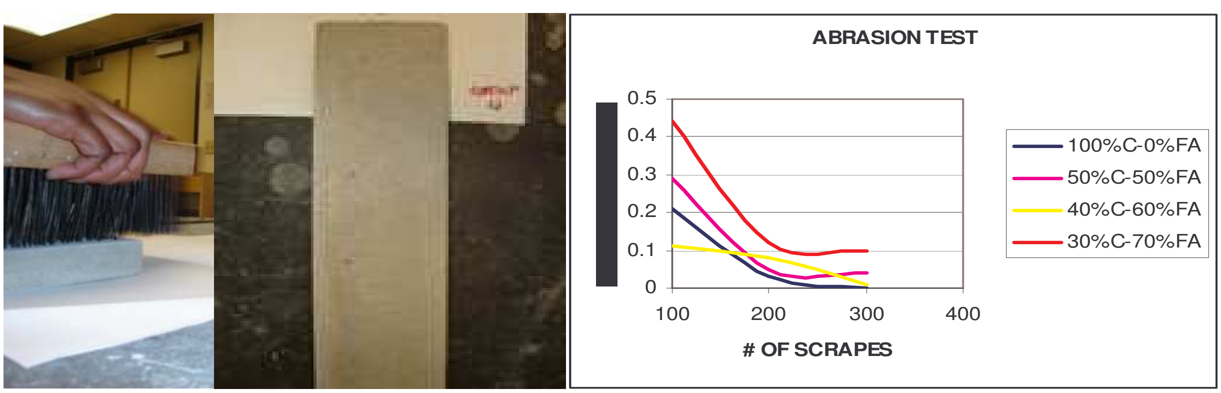


Figure 5: Scrapping test performed to a concrete plate to simulate the abrasion effect on concrete with different proportion of fly ash.

3. CONCLUSION

The studies developed in this research confirmed that concrete with high content of fly ash type F can reach the strength required to be considered structural concrete. It is observed that the larger the fly ash percentage in the concrete is, the longer it takes for the concrete to reach the desired strength. Concretes with high fly ash content may be improved reducing the water/cement ratio, and reducing the total water content in the mix. Concrete mixed with high fly ash content, low water cement ratio, and low water content, reached 5000 psi or more before 28 days, which is a good structural concrete.

The indirect tensile strength test results indicate that the ratio of tension and the square root of the compression strength trend to reduce when high fly ash content is used. This ratio reduces from 6.6 for the control group to 5.6 for concretes with high fly ash content. More research is needed to recommend an equation which considers the effect of the fly ash on the tension capacity.

Concretes with high fly ash content present significant reduction of the temperature released during the hydration process. Altogether, fly ash retards hydration; this may have effect in the time needed to make the finishing of some surfaces.

The workability of the concretes with high fly ash content is much better than the control group, reducing or eliminating the use of plasticizers, vibration and total water in the mix. The predominantly spherical shape of the fly ash particles helps to reduce the friction between particles.

The upper and non-formed surface of concretes with high fly ash content shows a dusty finishing. A qualitative scrapping test to simulate erosion is performed to the surface of plates indicating that concretes with high fly ash content release more dust than the control group; but, the amount of dust released trend to stabilize for a high number of scrapping passes. On the other hand, the resulting surface of cylinders with high fly ash content shows a shiny and smooth finishing, excellent for custom concretes styling.

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