Faculty of Engineering

EXPERIMENTAL STUDY ON THE EFFECT OF FLY ASH ON MECHANICAL PROPERTIES OF HIGH STRENGHT CONCRETE

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Judul: EXPERIMENTAL STUDY ON THE EFFECT OF FLY ASH ON MECHANICAL PROPERTIES OF HIGH STRENGTH CONCRETE

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Date

Dedicated to my father, mother, bros and honey

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ABSTRACT

The results of an experimental study on the effect of fly ash on mechanical properties of high strength concrete (HSC) is presented. Materials that have been used to produce high strength concrete mixture are as follows: (1) Cahaya Mata Sarawak ordinary Portland cement (OPC) that complies with the requirement of BS12; (2) Class F fly ash (FA) supplied by Sejingkat Power Station; (3) 10 mm maximum size granite for coarse aggregate; (4) fine aggregates were natural sand; and (5) superplasticizer was Sikament® NN manufactured by Sika Kimia. The study focused on HSC mixture with a fixed water/binder ratio of 0.37 and 400 kg/m^3 total of binder content. The levels of content of FA that have been choosen for this project were 0, 5, 10 and 15% from the total of binder content. The required dosage of superplasticizer (to achieve workable paste) for HSC with different levels content of FA was determined by conducting the flow test of mortar. Based on the optimum compressive strength obtained from cube compression tests, the optimum content of FA that could replace the cement content was assessed. The results obtained from the flow test show that the dosage of superplasticizer is decreased with an increasing of FA content. From the cube compression test results, the 10% of FA content was found to be the optimum percentage to replace the cement content. The results obtained from this investigation were found to be in general agreement with other published work.

ABSTRAK

Keputusan untuk pembelajaran eksperimen kesan *fly ash (FA)* dalam ciri-ciri mekanikal untuk konkrit berkekuatan tinggi dipersembahkan. Bahan-bahan yang telah digunakan untuk menghasilkan campuran konkrit berkekuatan tinggi adalah seperti berikut: (1) simen *Portland* biasa Cahaya Mata Sarawak yang mengikuti keperluan BS12; (2) *FA* kelas F yang dibekalkan oleh stesen penjana kuasa Sejingkat; (3) granite dengan sais maksimum 10 mm digunakan sebagai batu; (4) pasir yang digunakan adalah pasir semulajadi; dan (5) *superplasticizer* yang digunakan adalah Sikament® NN dihasilkan oleh Sika Kimia. Pembelajaran ini memfokuskan dalam campuran konkrit berkekuatan tinggi dengan nisbah air/pengikat 0.37 dan kandungan pengikat 400 kg/m^3 yang tetap. Peringkat kandungan *FA* yang dipilih adalah 0, 5, 10, dan 15% daripada jumlah pengikat. Dos *superplasticizer* (untuk mencapai kebolehkerjaan pada campuran) yang digunakan untuk konkrit berkekuatan tinggi dengan peringkat kandungan *FA* ditentukan dengan membuat ujian kebolehaliran. Daripada kuasa mampatan optimum yang didapati daripada ujian mampatan kiub, kandungan optimum bagi *FA* yang dapat menggantikan simen dikaji. Keputusan yang didapati dalam ujian kebolehaliran menunjukkan dos untuk *superplasticizer* menurun dengan peningkatan kandungan *FA*. Daripada keputusan ujian mampatan kiub, kandungan 10% *FA* merupakan peratus optimum untuk menggantikan kandungan simen. Keputusan yang diperoleh daripada kajian ini didapati termaktub dalam perjanjian awam dengan jurnal lain.

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1 INTRODUCTION

1.1 GENERAL

The purpose of this study was to investigate the effect of fly ash (FA) on mechanical properties of high strength concrete (HSC). Class F FA was used as a partial cement replacement on the HSC mixes. The developed HSC with FA was tested to determine its compressive strength. The main interest of the study is to investigate the optimum compressive strength of the HSC with different levels of content of FA. Thus, the optimum content of FA that could replace the cement content was assessed.

1.2 BACKGROUND

Nowadays, civil engineering is becoming more modern and advance. The discovery of HSC makes the work of engineer becoming easier in constructing a heavily loaded structure such as high rise building, bridges, off-shore platforms, and seismic resistant frames. The definition of HSC in quantitative term which is acceptable to everyone is not possible. Clearly then, the definition of HSC is relative and it depends upon both the period of time in question, and location (Mazloom et al., 2003). According to JKR Standard, usually the compressive strength of a normal concrete after 28 days can vary from 7 N/mm^2 to 40 N/mm^2. Therefore, the compressive strength of HSC in Malaysia can be determined as exceeding 40 N/mm^2 after 28 days.

High strength of a concrete could not be achieved by using the standard mixing of normal concrete. According to Mazloom et al. (2003), in order to achieved the concrete to be in the stage of high strength, water/binder ratio must be reduced, binder content must be increased, superplasticizers is required for the workability, and a low porosity and permeability material are desired. Nawy (2001) quoted that HSC can be develop from mixtures of cement, fine aggregate, coarse aggregate, water, and admixture and also additional superplasticizers. He also stated that, a certain mix proportion, the concrete can achieve certain strength. The strength of concrete can be increased with the help of an admixture. In the recent study of high strength concrete, an analysis has stated that, admixture can improve the strength of concrete. In order to reach the optimum strength, only certain amount of admixture is needed. The properties of a concrete can be generally divided into two that is the properties of fresh concrete and the properties of hardened concrete. The properties of fresh concrete consist of workability and stability. Meanwhile, the properties of hardened concrete consist of strength (compressive strength and tensile strength) and deformation. The properties of hardened concrete can also be known as the mechanical properties. Jackson and Dhir (1996) stated that the properties of fresh concrete are important only in the first few hours of its history, whereas the properties of hardened concrete assume an importance which is retained for the remainder of the life of the concrete.

FA is an artificial pozzolanas composed principally of amorphous silica with ranging amounts of the oxides of aluminum and iron and traces of other oxides (Brady et al., 1991). It is a fine dance powder of spheroid particles produced as the by-product of combustion of pulverized coal, and collected at the base of the stack. As an admixture it improves the workability of concrete, and in large amounts its pozzolanic action adds to the compressive strength. The advantages of using FA in concrete are FA is considerably cheaper than the cement, its use in concrete will result indirect economic savings, although indirect savings resulting from the conservation of energy and environment are of greater national interest. Takahashi (1999) quoted that, high strength is achieved by pozzolanas reaction when FA is replaced in a mixture of concrete. The effect of FA in HSC is improving durability due to miniaturization of the inside structure. Moreover, the cohesion of cement paste is lowered and concrete work is improved because the particles are spherical shape.

1.3 SCOPE OF PRESENT STUDY

The aims of this project were to investigate the physical and mechanical properties of HSC with FA. In accordance with the aims, the main objectives are as follows.

1. To determine required dosage of superplasticizer (to achieve workable paste) in HSC with different levels of content of FA by conducting the flow test of mortar.
2. To conduct the cube compression tests in order to determine the optimum strength of the HSC with different levels of content of FA.

Section 2 provides a review on the mix proportions and the compressive strength of HSC, and the characteristic and the influence of FA in HSC.

Section 3 describes the experimental investigation for the HSC with FA, which includes selection of materials, preparation of test specimens, and testing that was conducted to determine the required data.

Section 4 includes the results and discussion of the conducted experiments, which consist of flow test, slump test, and cube compression test results.

Section 5 contains the discussion and conclusions drawn in the project, and the recommendations for future study.

2 LITERATURE REVIEW

2.1 GENERAL

In order to have a better understanding of the relationship between HSC and FA, a review on the characteristic of concrete strength and application of HSC will be covered in this section. These include the study on the mix proportion of HSC, the compressive strength of HSC, the general characteristics of FA, and a review of the effect of FA on HSC.

2.2 HIGH STRENGTH CONCRETE

2.2.1 Mix proportions

In the year 2004, HSC has become popular in constructing a very demanding strength building such as high rise building, dams, bridges, and etc. Due to the development of this HSC, there are many type of procedure in the mix proportions of the concrete. This sub section will cover about the types of mix proportion and the materials used in HSC.

According to Takahashi (1999), the mix proportion of HSC consists of several elements that are cement, water, coarse aggregates, fine aggregates, admixtures, and superplasticizers. Each of these elements has their own ratio that can produce a certain grades of concrete strength. It is necessary to develop strength of cement paste, strength of aggregates, and bond strength of boundary surface between cement paste and aggregates in order to increase concrete strength. It was also mentioned that it is most important to improve the strength of cement paste, whereby if the strength of cement paste can be amended. Therefore bond strength can improve automatically. Figure 2.1 shows a classification of technique in developing HSC.

ACI Committee 211 (1997) quoted that the production of HSC that consistently meets requirements for workability and strength development places more stringent requirements on material selection than for lower strength concretes. Neville and Brooks (1987) reported that conventional concrete can be made to have strength of up to 100 N/mm^2 at 28 days, by using good quality and well-graded aggregates. The fundamental parameter is low porosity which is achieved by cement content in excess of 500 kg/m^3 of concrete, low water/cement (w/c) ratio (< 0.35), and by adequate compaction and curing. He also added, to achieve a normal workable mix, a superplasticizer is necessary.

In order to produce very high strength and workable structural concrete an experimental is done by using local natural pozzolan (NP) and silica fume (SF) (Shannag, 2000). Therefore, two high strength mortar mixes were used. The first mix proportion contained 15% SF and different proportions of NP (0, 5, 10, 15, 20, and 25%). The other mix contained 15% of NP and different proportions of SF (0, 5, 10, 15, 20, and 25%). The details on the mix proportion are on Table 2.1.

Mazloom et al. (2003) presented that the mix proportion of a cementitious material used were ordinary Portland cement (OPC) and SF. The chemical compositions and physical properties of OPC and SF are given in Table 2.2. For the detail of the mix proportion for the concrete which contain different level of SF are shown in Table 2.3. Crushed granite sand and gravel with nominal maximum size of 10 mm were used as aggregates. The w/c ratio and the slump of control HSC were 0.35 and 100+10 mm, respectively. The superplasticizer used is based on melamine formaldehyde and lignosulfonate. The dosage of the superplasticizer changed due to the effect of the different levels of SF.

According to Haque and Kayali (1998), six mixes were decided to use total cementitious material contents of 400 and 500 kg/m^3 of concrete and to replace cement by fine fly ash (FFA) on equal weight basis by 0, 10, and 15%. For all the concretes made, superplasticizer was used at a dosage of 1.51 per 100 kg of the total cementitious materials. The coarse aggregate used was 10 mm crushed granite with a sand/total aggregate ratio of 0.4. The mixture designs are shown in Table 2.4.

Jianyong and Tian (1997) reported that four concrete mixtures were proportioned with the following materials: (1) The cement was Chinese 525# Portland cement; (2) The binders used were ground-furnace slag and silica fume; (3) The coarse aggregate was gravel with the maximum particles size 30 mm; (4) The fine aggregate was graded silica sand with fineness modulus 2.8; (5) The superplasticizer was a dry naphthalene powder product with a water reducing rate is about 20% at the dosage of 1.0% of the cement. The mix design is tabulated in Table 2.5.

2.2.2 Compressive strength

In general, the properties of strength are important and the strength of the concrete is equal with the quality of the concrete. The greater the strength is, the more quality the concrete can be. According to Jackson and Dhir (1996), the compressive strength of concrete is taken as the maximum compressive load it can carry per unit area. Concrete strength of up to 80 N/mm^2 can be achieved by selective use of the type of cement, mix proportions, methods of compaction and curing conditions.

There are many properties that can affect the compressive strength of HSC. According to Takahashi (1999), showed that the relationship between water-binder ratio and compressive strength under the conditions that unit water is between 145 to 175 kg/m^3, water-binder ratio between 15 to 40% and with the addition of silica fume or ground granulated furnace slag (see Figure 2.2). Moreover, the compressive strength increases proportionally with binder water ratio in the range of water-binder rate with more than 25% but decreases with the increase of binder-water ratio in the range of water-binder rate with less than 25%. Figure 2.3 show that even though the w/c ratio is the same, a small amount of unit water increases the compressive strength rather than a large amount of unit water. This means that a smaller amount of unit water is necessary for an increase in the use of high-range AE water-reducing agent in order to maintain the same slump. As a result, the compressive strength became higher owing to the good dispersion of cement. Figure 2.4 presents that the maximum compressive strength is at 20 to 30% of silica fume and 30 to 50% of ground granulated furnace slag.

According to Wee et al. (1995), various admixture was used such as SF, ground granulated blast furnace slag (BFS) and an ettringite-based cementitious material (Hi-Fi). With the comparison of ordinary Portland cement (OPC), Figure 2.5 shows the result of compressive strength of concrete with and without various mineral admixtures. Jianyong and Tian (1997) concluded that concrete can improve compressive strength when its slump is kept unchanged, and the dosage of slag (S) and SF both vary 10% to 15% of the total weight of bonding materials. Table 2.6 shows the compressive strength of concretes. Whereby, Concrete A did not contain any S or SF, and the other concrete were three types of substitution: 15% SF plus 10% S, 10% SF plus 15% S, 5% SF plus 20% S; that were mark as Concrete B, Concrete C, and Concrete D, respectively.

Haque and Kayali (1998) had conducted an experiment with all of the six concretes achieved high strength, as even the 7-day compressive strength varies from 60 to 84 N/mm^2. The 28-day strength varies from 74 to 111 N/mm^2. Again consistent with water/cementitious ratio and the optimum addition of 10% FFA for workability, this optimum value holds for strength development as well. Accordingly, in both the 400 and 500 series of concrete 10% replacement of cement with FFA give the highest result 28-

day strength of 94 and 111 N/mm^2, respectively. Table 2.7 shows the result of the compressive strength.

Compressive strength is developed from time to time in the life spans of a concrete. However, it had no influence on long-term strength of wet-stored concrete. According to Mazloom et al. (2003), compressive strength of concrete rapidly develops until 28 days, after the 28 days the development of compressive strength is slow. Table 2.8 shows the development of compressive strength with age.

2.3 Fly Ash

2.3.1 General characteristics

FA is the most commonly used pozzolanas in HSC, besides silica fume and slag. Jackson and Dhir (1996) quoted that, because of their reaction with lime, which is liberated during hydration of Portland cement, these materials can improve the durability when added to concrete. Table 2.9 shows the specification for FA for use in concrete.

According to Nawy (2001), FA can be divided into two classes, which are Class F and Class C. In Class F the sum of SiO_2, Al_2O_3, and Fe_2O_3 is 70% or greater. This class normally has low calcium oxide content, but a high proportion of high silica content. The particle ranges from 1 μm to 1 mm or greater, with a specific gravity of solid fly ash particles normally ranging between 2.2 and 2.8. Meanwhile, in Class C the sum of SiO_2, Al_2O_3, and Fe_2O_3 is equal to or greater than 50% but equal to or less than 70%. It has high calcium oxide content. It also has a high proportion of particles finer than 10 μm.

According to Takahashi (1999), it should be noted that FA might affect the color of the resulting concrete, the carbon in the ash making it darker. This may be of importance from the standpoint of appearance, especially when concrete with and without FA is placed side by side. The behavior of high-lime ash is sensitive to temperature. Especially, in mass concrete when a rise in temperature occurs, the products of reaction may not be of high strength. However, the development of strength is not simply related to temperature, being satisfactory in the region of 120 to 150 °C but not at about 200 °C when the products of reaction are substantially different.

2.3.2 Effect on high strength concrete

According to Nawy (2001) FA can affect concrete in two stages, which are on fresh concrete stage (consists of workability, bleeding, time of set, and the need of superplasticizer) and on hardened stage.

On fresh concrete stage, firstly FA can affect the workability of the concrete. Which is whenever FA is used, the volume of cement and FA in the concrete mixture would normally exceed than in no-FA concrete mixture. The increased volume produces larger cementitious paste volume, hence better workability. As a result, a lower content is needed than in mixtures where FA is not used. Secondly the bleeding, which is FA generally reduces bleeding, as it provides greater fines volume and produces a lower water content in the mixture. Next is the time of set, which is the time of set is influenced by the ambient and concrete temperature, cement type, water/cement ratio, percentage of FA that replaces the cement in the mixture, and use of other admixtures in addition to FA. Lastly the need of superplasticizers, which is superplasticizer are necessary in high-volume FA concrete, where the ratio water/binder is 0.3. The dosage is needed is a function of the required slump, generally about 1.5% of the total cementitious material. A superplasticizer that will not delay the setting time should be chosen for mixture.

The effect of FA on hardened concrete consist of compressive strength, modulus of elasticity, long-term behavior, air entrainment, freezing and thawing resistance, alkali-silica reaction, and sulfate resistance (Nawy, 2001). According to Takahashi (1999), the use of Class F FA can result in a lower compressive strength at early ages (3 to 7 days). Thereafter, as the strength contribution rate of the Portland cement decreases, the continued pozzolanic activity of FA content in the hardening mixture contributes to higher strength gain at later ages. This higher rate of strength gain continues with time, resulting in higher ultimate strengths than in concretes without FA content. The usage of Class F FA in concrete can produce a strength ranging from 8 to 38 N/mm^2 at early age, depending on the mix proportioning of the experiment (Nawy, 2001). On the other hand, Class C FA sometimes exhibit at early ages a lower strength concrete, although they are more reactive than Class F FA at early age because of the presence of $Ca(OH)_2$ (Nawy, 2001). Figure 2.6 shows the rate of strength for Class C FA concrete compare with no-FA concrete.

According to Haque and Kayali (1998), 10% replacement of cement with Class F FA resulted in about 20% increase in strength. Accordingly, the use of Class F FA is not only technically superior in terms of producing HSC, but is environment friendly as well. Table 2.8 shows the result of the experimental study. Gopalan and Haque. (1990) reported a compressive strength and water penetration of three grades of HSC with cement contents raging from 400 to 500 kg/m^3 and superplasticizer. The control mixes were redesigned by adding a Class F FA at 15 and 35% by weight of cement is replaced. All concretes were designed with the same workability. The strength development was monitored in three curing regimes. The curing conditions significantly influenced the strength development and the water penetration of the concretes. An optimum 15% replacement of FA was found to be appropriate for the concretes. Larger amounts of FA were found undesirable for high strength development. Figure 2.7 shows the result of variation strength of 28 day.

2.4 SUMMARY

This section led to the following summary.

1. The binder content for HSC must not less than 400 kg/m^3.
2. The w/c ratio must range from 0.27 to 0.55.
3. The coarse aggregate selection must range from 10 to 20 mm, and the sand/total aggregate ratio is 0.4 (depend on size of coarse aggregate).
4. Proportioning of partial cement replacement usually range from 10 to 40 percent by weight of the cement (depends on the types of materials).
5. Slump test design for < 50 N/mm^2 must be ≤ 210 mm, for ≥ 50 N/mm^2 must be $\leq$ 230 mm, and for ≤ 60 N/mm^2 slump must be ≤ 500 mm (flow).
6. Superplasticizer maximum dosage is 5 % by weight of the cement.

TABLES

Table 2.1: Mix proportion and compressive strength (Shannag, 2000)

Mix no.	Mix proportions (by weigh of cement)						Compressive strength (N/mm^2)		
	C	SS	SF	P	W	SP	3 days	7 days	28 days
1	1.00	0.60	0.00	0.15	0.35	0.02	50	58	69
2	1.00	0.60	0.05	0.15	0.35	0.02	45.5	65.5	81
3	1.00	0.60	0.10	0.15	0.35	0.02	50.5	66.5	84.5
4	1.00	0.60	0.15	0.15	0.35	0.03	65.5	75	110
5	1.00	0.60	0.20	0.15	0.35	0.04	56.5	75	95
6	1.00	0.60	0.25	0.15	0.35	0.04	55.5	73.5	88.5

*__C__- Cement, **SS**- Silica sand, **SF**- Silica Fume, **P**- Pozzolan, **W**- Water, **SP**- Superplasticiser

Table 2.2: Chemical composition and physical properties of cementitious materials (Mazloom et al., 2003)

Item	Cementitious materials, %	
	Ordinary Portland cement	SF
SiO_2	21.46	91.70
Al_2O_3	5.55	1
Fe_2O_3	3.46	0.9
CaO	63.75	1.68
MgO	1.86	1.8
Cl	-	0.08
SO_3	1.42	0.87
K_2O	0.54	-
Na_2O	0.26	-
LOI	-	2
	Compounds	
C_3S	50.96	
C_2S	23.1	
C_3A	8.85	
C_4AF	10.53	
	Fineness	
SSA (m_2/kg)	330	14,000