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MECHANICAL PROPERTIES OF HIGH STRENGTH CONCRETE AT HIGH TEMPERATURE LOADING

ZURAIMI BIN JOHARI

A project report submitted in partial fulfillment of the
requirement for the award of the degree of
Master of Engineering Civil (Structure)

Faculty of Civil Engineering
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OCTOBER 2005

I declare that this thesis entitle "*Mechanical Properties of High Strength Concrete at High Temperature Loading*" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name : ZURAIMI BIN JOHARI

Date : 30th OCTOBER 2005

To my beloved wife, children and all family

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ABSTRACT

The research effort aim characterized the mechanical behavior of high strength concrete at high temperature loading. Mechanical behaviors of two different type of concrete were measured after heated to 200^0C, 400^0C, 800^0C and 1000^0C. The average compressive strength of these two types of concrete before being too exposed to the high temperature is 30MPa and 60MPa.

The following physical behaviors were measured for each concrete specimen prior to high temperature exposure: physical dimension, mass (initial mass, heated mass and total mass loss) and longitudinal resonance frequency (before and after heating). Before heating specimens until the selected temperature, a baseline data or control data set was generated for each type of concrete after exposure to a nominal room temperature (25^0C).

The selected temperatures were accomplished by placing the specimens into a low temperature electrical furnace for temperature below than 300^0C and used high temperature electrical furnace for temperature greater than 300^0C. Then the specimens will heat with rate of heating 200^0C per hour or 5^0C per minute until reached steady state condition at one of selected temperature. Specimen will heat with a total heating period of 7 hours before cooled to room temperature for 24 hours. The specimens were weighed and resonance frequency was measured again (after heating). The compressive strength of each specimen was measured. Result from this research may be useful for assessing post fire behavior properties of high strength concrete.

ABSTRAK

Penyelidikan ini adalah bertujuan untuk mengkaji sifat-sifat mekanikal konkrit berkekuatan tinggi apabila dibakar pada suhu yang tinggi. Sifat mekanikal konkrit hanya bertumpu pada suhu 200^0C, 400^0C, 800^0C dan 1000^0C. Dua jenis konkrit akan digunakan didalam penyelidikan ini iaitu kunkrit grad 30 MPa dan konkrit grad 60 MPa.

Sifat fizikal konkrithanya bertumpu kepada ukuran dimensi fizikal, berat (erat permulaan, berat selepas di baker dan jumlah kehilangan berat) dan perintangan frekunsi resonan (sebelum dan selepas di baker). Sebelum specimen dibakar, data ujuan di perolehi akan digunakan sebagai data kawalan bagi kedua-dua jenis konkrit. Pembakaran specimen akan menggunakan dua jenis oven relau iaitu relau bersuhu rendah (kurang dari 300^0C) dan relau bersuhu tinggi (lebih dari 300^0C). specimen akan di baker pada kadar 200^0C sejam atau 5^0C seminit. Pembakaran anak dijalankan selama tujuh jam sebelum di biarkan menyejuk pada suhu bilik selama 24 jam. Berat dan frekunsi resonan disukat sekali lagi (sesudah dipanaskan). Setelah itu ujian mampatan dijalankan. Data dan keputusan penyelidikan ini boleh digubakan untuk melihat kesan konkrit berkekuatan tinggi setelah dibakar pada suhu yang tinggi.

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CHAPTER 1

INTRODUCTION

1.0 Introduction

Fire induced collapsed of the world trade centre (WTC), New York on 9th September 2001was highlighted that the important of performance construction materials at high temperature loading especially for the high rise building.

The high strength concrete (HSC) is a materials often used in high rise building structure design. HSC can be manufactured by most concrete plane using the state of additives such as silica fume and super plasticizer or water reducing admixture. In the high rise building structure, the HSC offer significant economical and achievement advantages over ordinary concrete or normal strength concrete (NSC).

However, results of many recent fire tests have shown that there are much different this of two types of concrete HSC and NSC during the high temperature exposure. These include the different in mechanical behavior properties such as compressive strength retained by HSC and NSC at high temperature. HSC specimen show fail by explosive spalling when subjected to rapid heating.

"Malhotra (1956), Zoldners (1960), Davis (1967), Abrams (1971), Faiyadh (1989),Khoury (1992) and Noumowe et. Al (1994) has reported the effect of high temperature exposure on the properties of concrete. Several mechanism have identified for the deterioration of concrete due to high temperatures. These include decomposition of the calcium hydroxide into lime and water, expansion of lime on re-hydration, destruction of gel structure, phase transformation in some types of aggregate and development of micro cracks due to thermal incompatibility between cement paste matrix and aggregate phase"

The type of aggregate also influenced the response of concrete to high temperature. On this research, assumes that all the aggregate and other materials used follow the British Standard, ASTM or equivalent.

At the end of this research, the mechanical behavior of HSC exposure in high temperature will know and it will assist in the development of new standard for used the HSC. These data produced may be being able to assist in the development of new formulation of HSC that are less prone to explosive spalling.

1.1 Objective

Generally the main objective of this research is to study the mechanical properties of high strength concrete after heated in high temperature. In detail the objective of this research as a following:

- To find out the mechanical behavior of High Strength Concrete at temperature 200^0C to 1000^0C
- Determine the percentage of HSC strength reduction by increasing temperature loading from 200^0C to 1000^0C with rating 200^0C per hour.
- Determine a systematic comparison of result of high temperature test on Normal Strength Concrete (NSC – grade 30 MPa) and High Strength Concrete (HSC – grade 60 MPa) specimen to examine the effect of high temperature exposure to the mechanical properties of concrete with different original compressive strength.

1.2 Scope of Research

The mechanical properties of high strength concrete at high temperature influenced by type of aggregate properties, water content, admixture content and etc. in this research, the scope will covered following:

- Concrete design mix for both type of concrete is used BS 8110. The types of concrete to be used, 30MPa & 60Mpa. The entire test involved before heated in high temperature will be conduct and the result of testing will be used as a controlled data.

- Only the ***unstressed residual property test*** will be done which mean the specimens allowed to cool down within 24 hours after heated on the target temperature.

Value of the compressive strength will be recorded and analyzed for the temperature 200^{0}C, 400^{0}C, 800^{0}C and 1000^{0}C or until specimens explode which reached first

1.3 Research Methodology

The research methodology started from find the problem and then to resolved the problem. All stage to get the result as shown in the following Figure 1.

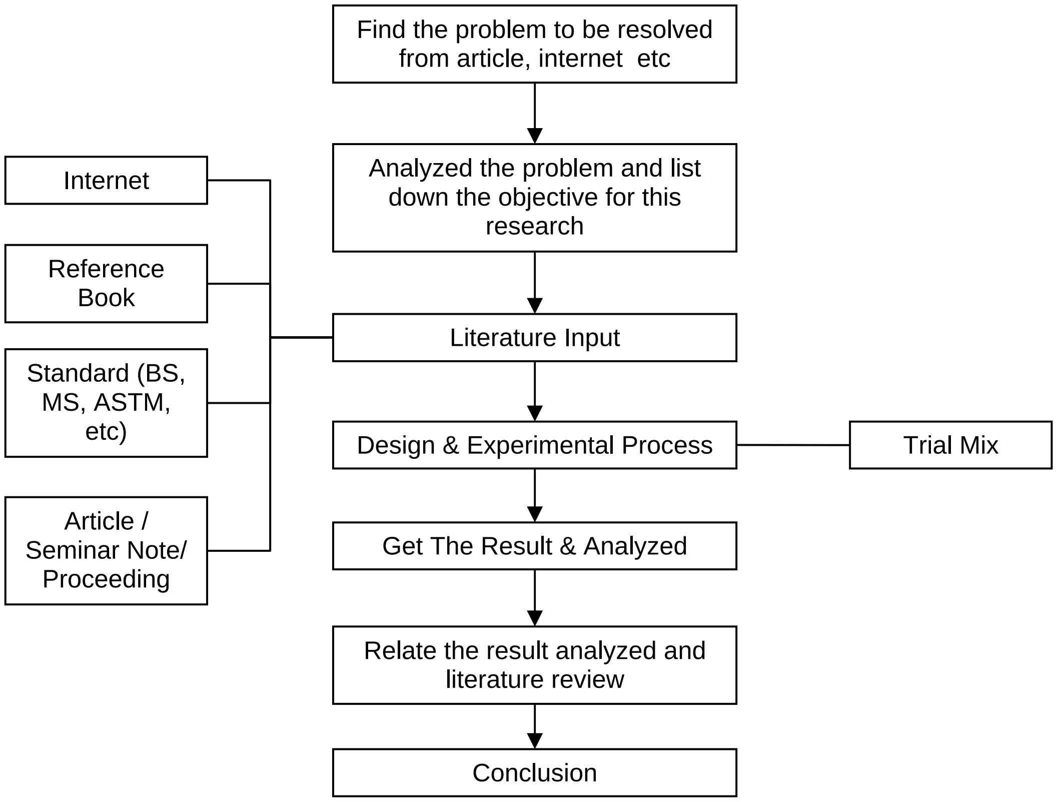

Figure 1: Research Methodology Flow Chart

CHAPTER 2

LITERATURE REVIEW

2.0 Concrete Materials

2.0.1 Cements

The most widely used cement in country is ordinary Portland cement. Heating limestone and clay or other suiTable raw materials together from a clinker rich in calcium silicates makes it. The clinker is ground to a fine powder with small proportion of gypsum (calcium sulfate), which regulates the rate of setting when the cement is mixed with water.

By incorporating other materials during manufacture generally when the clinker is being ground an even wider range of cement is produced Portland blast furnace, masonry, colored, oil well, water repellent and hydrophobic cement.

The choice of Portland cement for high strength concrete is extremely important. Unless high initial strength is the objective such as in pre stress concrete, there is no need to use a type III cement. The different brand will have different strength development characteristics because of the variation in compound composition and fines that are permitted by ASTM C 150.

Initially silo test certificate should be obtained from potential supplier for the previous 6 to 12 month not only gives an indication on strength characteristic from the ASTM C 109 mortar cube test. If the tricalcium silicate contents various by more than 4 percent the ignition loss by more than 0.5 percent or the fines by more than 375 cm^2 / g then problem in maintaining a uniform high strength may result. Sulfate level should be maintained at optimum with variation limited to ± 0.20 percent.

High cement content can be expected to result in a high temperature rise within the concrete. For example the temperature in the 1.2 m square column used in water tower place, which contained 502 kg/m3, rose to 66^0C from 24^0C during hydration. The heat was dissipated within 6 days without harmful effect. Howe ever when the temperature rise is expected to be a problem a type II low heat of hydration cement can be used, provided it meets the strength producing requirements.

A further consideration is optimization of the cement admixture system. The exact effect of a water reduction agent on water requirement for example will depend on the cement characteristic and cement content. The following Figure has shown an effect of cement on compressive strength.

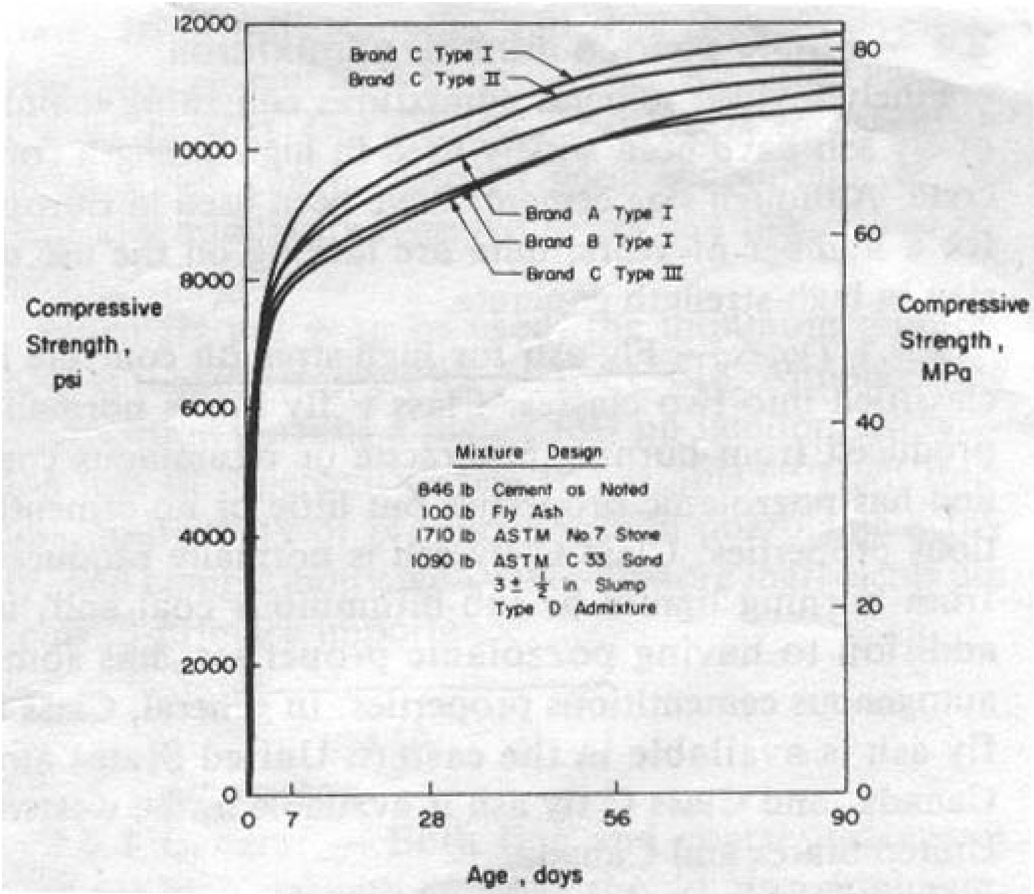

Figure 2: Effects of Concrete Compressive Strength [High Strength Concrete, 1987]

2.0.2 Aggregate

The term ‘aggregate’ is used to describe the gravel, crushed stones and other materials, which are mixed with cement and water to make concrete. As aggregate from the bulk of the volume of concrete the selection of suiTable materials is important. Gravel, sand and crushed stone such as granite blast and the harder type of limestone and sand stone, are in common use as aggregate. A list and their petrological group is given in section 2 of BS 812 which is describe test for ascertaining whether the aggregate is suiTable for concrete works, but for natural aggregate the test result are given in BS 882.

2.0.2.1 Essential requirement

The most important for aggregate to use in concrete are durability and cleanness.

For the durability, aggregate should be hard and not contain materials, which are likely to decomposed, or change the volume when exposed to the weather or to affect the reinforcement. Aggregate must be free from undesirable materials such as coal, pyrites and lumps of clay: coal may swell; pyrites may decompose causing iron oxide stain to appear on the concrete surface. In high strength concrete, the crushing value or impact value, density or mineralogical type may be specified.

Aggregate also should be clean and free from organic impurities. High containing organic materials in aggregate make poor concrete. The particles should be free from coating of dust or clay, as these prevent the proper bonding of materials. Gravel and sand are usually washed by the supplier to remove clay, silt and other impurities materials. However washing must not be carry to such as extend that all fine materials passing the 300μm.

2.0.2.2 Particle Shape

Many studied shown the crushed stone produces high strength then round gravel. The reasons for this are because the greater mechanical bond which can develop with angular particles.

2.0.2.3 Size of aggregate

The size of aggregate normally governs by the type of work to be done. For reinforced concrete it should be such that the concrete can be placed without difficulty surrounding all reinforcement and filling the corners of the formwork. The course aggregate for reinforce concrete have nominal maximum size of 20mm

In massive structure sometimes used the larger piece of aggregate known as ‘plums’.

2.0.2.4 Grading of aggregate

Aggregate can be graded in two grades. First grade is fine aggregate and the other is coarse aggregate.

The optimum grading of fine aggregate for high strength concrete is determined more by its effect on water requirement than on physical packing. The sand with a fineness modulus below 2.5 gave the concrete a sticky consistency making it difficult to compact. Sand with fineness of about 3.0 gave is the best workability and compressive strength.

High strength concrete typically contains such high content of fine cementations materials that the grading of the aggregate used relatively not important compare to normal or conventional concrete. A national Crushed Stone Association recommended in the interest of reducing the water requirement. The amount passing the no 50 and 100 sieves should be kept low but still within requirement of ASTM C33.

For the type of coarse aggregate, shown that for optimum compressive strength with high cement content and low water cement ratios the maximum size of coarse aggregate should be kept to a minimum at 12.7mm or 9.5mm. Maximum size is within 19 mm to 25.4mm.

Reported by previous researcher *Cordon and Gillespie* felt that the strength increased were causes by reduction in average bond stress due to the increased surface are of the individual aggregate. *Alexander* found that the bond to a 76mm aggregate particle was only about 0.1 of that to 13mm particle. He also stated that except for very good or very bad aggregate the bond strength was about 50 to 60 percent of the paste strength at 7 days. Smaller aggregate also considered producing higher concrete strength because of less severe concentration of stress around the particles, which are caused by, different between the elastic moduli of the paste and the aggregate. Table 1 and 2 shown the grading limit for both of aggregate type, which is derived from BS 882