A STUDY ON HIGH PERFORMANCE CONCRETE USING SANDSTONE AGGREGATES

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The materials in this thesis are original except for quotations, excerpts, summaries and references, which have been duly acknowledged.

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ABSTRACT

An investigation into the potential use of crushed sandstone aggregates in high performance concrete (HPC) has been carried out. A suitable mix design of HPC has been developed using crushed sandstone coarse and fine aggregates. The engineering properties of both fresh and hardened HPC have been obtained by conducting tests on slump, air content, fresh concrete density, compressive strength, flexural strength and modulus of elasticity. The long-term compressive strength performance of HPC has been studied. The flexural behaviour such as ultimate load capacity, deflection and crack width at service load, deflection and curvature ductility, and position of neutral axis have been determined on prototype reinforced HPC beams at two points load. The durability performance of hardened concrete has been conducted by doing the sorptivity, absorption and permeable pore voids, rapid chloride penetration test, chloride diffusion by 90-day salt ponding and, wet and dry cycle. In this investigation three types of curing conditions have been employed to see the effect of curing on strength and durability. The most satisfactory performance in engineering properties on HPC is observed in full water curing. Combination of silica fume and fly ash as partial replacement of cement with crushed sandstone aggregates found to synergistic effects on workability, strength and durability on HPC. This investigation concludes that locally available sandstone aggregates can be used in HPC production. In future, the prospect for resource utilization of marginal quality sandstone aggregates in HPC can be explored further.

ABSTRAK

KAJIAN KE ATAS KONKRIT BERKEKUATAN TINGGI MENGGUNAKAN AGREGAT BATU PASIR

Satu penyiasatan telah dijalankan ke atas potensi penggunaan agregat batu pasir hancur dalam Konkrit Prestasi Tinggi (HPC). Rekabentuk campuran HPC yang bersesuaian telah dibentuk dengan menggunakan agregat batu pasir hancur kasar dan halus, sifat-sifat kejuruteraan kedua-dua HPC segar dan keras telah diperolehi dengan melakukan ujian ke atas runtuhan, kandungan udara, ketumpatan knokrit segar, kekuatan mampatan, kekuatan lenturan dan modulus keelastikan. Prestasi kekuatan jangka panjang HPC telah dikaji. Sifat kelenturan seperti kapasiti beban akhir, pembengkokan dan keretakan keluasan pada beban servis, pembengkokan dan kemuluran kelengkungan, dan posisi paksi neutral telah ditentukan ke atas protaip rasuk HPC bertetulang pada beban dua titik. Prestasi ketahanlasakan konkrit keras telah dilakukan dengan menjalankan ujian "sorptivity", penyerapan dan liang kosong telap, ujian penusukan klorida cepat, resapan klorida pada 90 hari perendaman garam dan kitar basah dan kering. Dalam penyiasatan ini, tiga jenis keadaan pengawetan telah digunakan untuk melihat kesan pengawetan ke atas kekuatan dan ketahanlasakan. Prestasi yang paling memuaskan dalam sifat kejuruteraan telah diperhatikan pada HPC yang diawetkan dalam pengawetan air sepenuhnya. Kombinasi fume silika dan debu terbang sebagai pengganti separa simen bersama agregat batu pasir hancur didapati mempunyai kesan sinergi ke atas kebolehkerjaan, kekuatan dan ketahanlasakan ke atas HPC. Penyiasatan ini menyimpulkan bahawa agregat batu pasir hancur tempatan boleh digunakan untuk penghasilan HPC. Pada masa hadapan, prospek penggunaan sumber agregat batu pasir yang berkualiti margin boleh diterokai dengan lebin lanjut dalam HPC.

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CHAPTER 1

INTRODUCTION-HIGH PERFORMANCE CONCRETE AND AGGREGATES

1.1. High Performance Concrete

High performance Concrete (HPC) is known as a high technology construction material, proving to be very cost effective, reliable, and having long term durability in natural environment. The study of HPC has been an extremely active research area in recent years. The definition of HPC is based on establishing value of workability, strength and durability. Broadly speaking, HPC is defined as "concrete made with appropriate materials combined according to a selected mix design and properly mixed, transported, placed, consolidated, and cured so that the resulting concrete will give excellent performance in the structure in which it will be exposed, and with the loads to which it will be subjected for its design life" (Forster, 1994a).

With the development of HPC, the strength and durability of concrete has improved largely. Although HPC offers many advantages, due to the restriction of the manufacturing process and the availability of quality raw materials, the development of HPC is still limited.

In high-rise buildings and bridges, the stiffness of the structure is of interest to structural engineers. On certain projects the minimum modulus of elasticity has been specified as a means of increasing the stiffness of the structure. The modulus of elasticity is affected significantly by the properties of aggregates and mix proportion (Balbakki et al., 1991). The highest possible of modulus can be obtained through the use of good quality coarse and fine aggregate from the same source (Kosmatka *et. al.,* 2002).

According to Neville (1997), the aggregate with low modulus of elasticity is more beneficial with respect to HPC. There is a growing interest in substituting alternative materials in concrete and HPC. Hence, the innovative technological developments in the field of waste materials derived from industrial by-products have increased to improve the HPC properties.

1.2. Function of Aggregates

Aggregates both coarse and fine are considered to be inert fillers for concrete to reduce the amount of cement required. The characteristics of aggregate play the substantial role in the fresh and hardened properties of concrete as it occupies about 50 to 80% of total concrete volume. It is commonly accepted that the properties of aggregates used in HPC have great influence on the mechanical properties and durability (Aitcin, 2003). In general, the coarse aggregate used in HPC should be hard, dense, non-reactive and durable. The fine aggregate should be free from organic impurities, clay or silt and relatively coarser sand with fineness modulus in the range 2.5 -3.2 is recommended (Nawy, 2001). A higher degree of fine and coarse aggregate packing requires less water and thus increasing the concrete quality.

1.3. Crushed Stone Sand

Due to depletion of river sand in the use of concrete and environmental pressure on solid waste disposal, the use of crushed stone sand, commonly known as quarry dust (solid waste) is considered a viable alternative to river sand in concrete. Crushed stone sand is a fine material formed during the process of conversion of rock into aggregate and has particle size ranging from 4 mm to dust size (< 0.075 mm). The crushed stone sand is a material of high quality. The fine particles and irregular shape of the crushed stone sand has harsh effects on the workability and finishability of concrete. These harsh effects have given crushed stone sand a poor reputation in the construction industry. However, recent studies have shown that this crushed stone sand can be used to produce concrete with higher compressive and flexural strengths (Bonavetti *et. al.,* 1994, Celik *et. al.,* 1996).

The crushed stone sand based on its quality, can replace 15 to 60 % of total fine aggregate in concrete (Mannan *et. al.,* 2001, Mulu *et. al.,* 2003). The use of crushed stone sand is desirable from the social and environmental view point. It also needs to be economically and technically viable.

1.4. Importance of Study

Due to the increased level of construction in Malaysia in the forthcoming years, it is expected that fine aggregate suitable for use in concrete will become scarce or not economical to produce. As sources of quality concrete aggregate become depleted, the use of more marginal aggregates will mean an increased use of reactive aggregates in concrete.

In Sabah, Malaysia, the average annual production of stone aggregates including river pebbles is about 12 million tonnes. Crushed sandstone aggregate is about 6.5 million tonnes of total aggregates, which is more than 54 %. During the crushing process at the quarry, about 22 % of the particle has the size 3 mm to dust which is known as crushed sandstone sand (Hisam *et. al.,* 2002). Sandstone sand consists of about 85% sand sized material and 15 % of silt and clay.

In places where there is a scarcity of suitable materials for HPC the economic considerations may necessitate experimenting with suitable locally occurring substitute materials. But some aggregates can cause detrimental effect on durability performance of the concrete. Sandstone is a reactive material, which has detrimental effect on concrete durability. One of the major concerns with such aggregate is the alkali-silica reaction. This has raised the concern now when the concrete industry is forced to develop durable concrete with local available sources.

1.5. Alkali-Silica Reaction

Alkali-silica reaction (ASR) occurs either in mortar or concrete. ASR is a deleterious chemical reaction between hydroxyl (OH^-) ions associated with alkalis (sodium and potassium) present in cement or other sources and certain reactive siliceous components that may present in aggregates, producing the gel. When this alkali-silica gel absorbs moisture, it expands, and eventually produces cracks in aggregate particles as well as in the cement paste in concrete (Prezzi *et. al.,* 1997). It causes serviceability problem in concrete structures. The following three conditions must be satisfied for expansive ASR to occur:

1. A reactive form of silica or silicate must be present in the aggregate.
2. Sufficient alkali, sodium (Na) and/or potassium (K), mainly from cement, must be available.
3. Sufficient moisture, i.e., not less than 80% relative humidity (RH) in the pore structure of the concrete or mortar, is required.

1.5.1. Reactive Aggregate

It is the form of silica that determines whether a siliceous aggregate is reactive or not. Many of the coarse aggregates used in construction are siliceous in composition, i.e., high in silica (SiO_2) content. However, they are not necessarily reactive. Certain reactive aggregates do not exhibit maximum expansion unless the aggregate is present in critical range.

The proportion of reactive aggregate particles that produces maximum expansion for a given alkali content and water-binder ratio (w/b) in concrete is known as the pessimum proportion. For example, 3% opal (reactive mineral) in aggregate shows maximum expansion. With parameters such as alkali content, w/b, etc. being constant, the difference in expansion of different potentially reactive aggregates mainly depends on (i) inherent reactivity of their constituent mineral phases or rock types, (ii) grain size of the reactive particle, and (iii) proportion of these reactive phases within the reactive aggregate.

Not all aggregates that are susceptible to ASR, however, show the pessimum effect. Aggregates without this pessimum effect exhibit increasing expansion as a function of the amount of reactive particles present in the aggregate. Fine aggregate is more susceptible to ASR because of its higher surface area. Figure 1.1 shows the different forms of silica and their reactivity

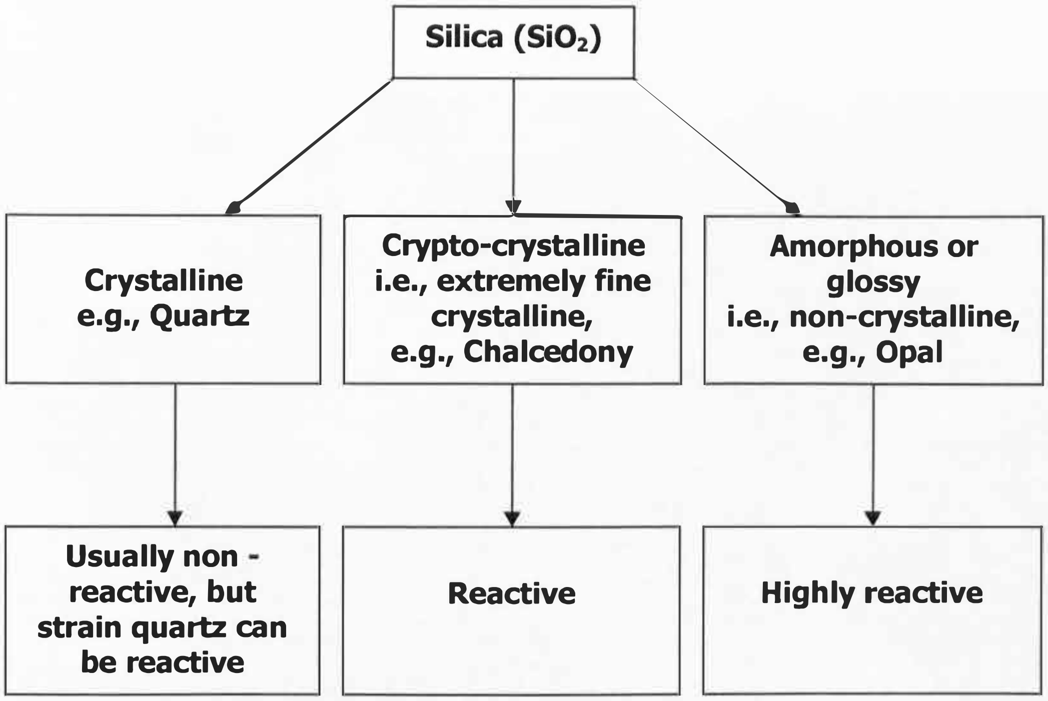
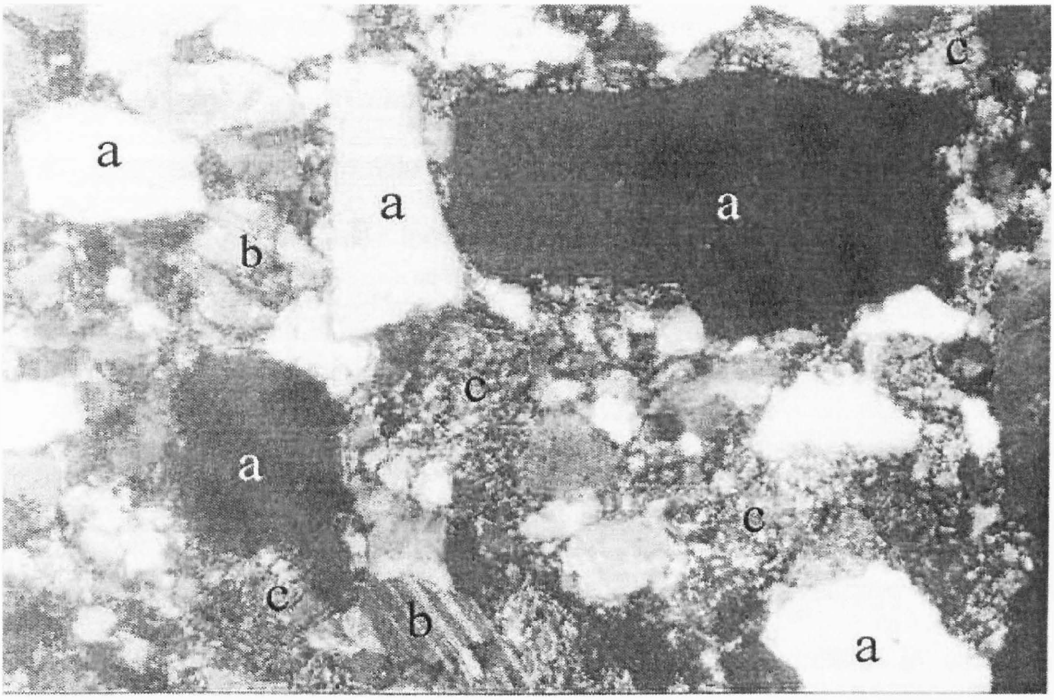


Figure 1.1: Forms of Silica and Their Reactivity

1.5.2. Petrography of Sandstone Aggregate

Petrography is a comparatively quick way to predict aggregate reactivity based on microscopic examination of aggregate samples. Mineral properties in aggregate determine aggregate reactivity. Photomicroscope image of sandstone aggregate is shown in Figure 1.2. A petrographical, mineralogical and textural description of the different sources of Kota Kinabalu quarried sandstone aggregate has the following characteristics (Felix, 1989). Thin-section studies showed that the sandstone consisted of 70 % quartz, 8 % chert, 15 % feldspar and less than 10 % rock fragments including sedimentary, metamorphic and igneous rock. The chemical compositions of sandstone aggregate are shown in Table 3.3, Chapter 3. It contains mainly silica 82 % and aluminum 9 % and all other compositions are marginal. The sandstones are poorly sorted, that is, grain of various sizes occurred together (0.03 to 3 mm). The frame work is dominated by quartz grains which are generally rounded to subrounded.



a - Silica; b - Feldspar; c - Rock fragments (Chert, igneous and metamorphic rock)

Figure 1.2: Photomicroscope Image of Sandstone Aggregate

The interstitial matrix consists of silt-sized quartz, mica, and probably also sub-microscopic clay minerals at grain interfaces. Internal porosity of sandstone is clearly enhanced adjacent to mica. In general, the sandstone is held together by phyllosilicate minerals (clay and altered rock fragments) due to local compaction and rarely by chemical cement, and it is relatively soft and friable. Coarser granularity and better crystallinity suggest that sandstone is less liable to silica dissolution. For the case of late or slow alkali-silica reaction with sandstones contains stained quartz and metamorphosed sediments such as phyllite, causes swelling of aggregate particles. This is the most common form of ASR, and there is a lack of literature on reactive mechanism, considered still under investigation.