A STUDY ON STRUCTURAL LIGHTWEIGHT CONCRETE USING OIL PALM SHELL (OPS) AGGREGATE

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DECLARATION

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 experimental investigation using waste oil palm shell (OPS) as renewable coarse aggregate in structural lightweight concrete was conducted. An optimum OPS concrete mix with slump of 50 to 70 mm, 28-day air-dry density of about 1965 kg/m^3 and 28-day compressive strength of more than 28 MPa was developed. The basic engineering properties which include the compressive strength, splitting tensile strength, modulus of rupture and modulus of elasticity of OPS concrete were compared with that of granite concrete (normal weight concrete). Four types of curing conditions were employed to determine its effect on the structural and durability properties of OPS concrete. The structural bond properties of OPS concrete were determined through the pull-out test incorporating different sizes and types of steel reinforcement up to an age of 180 days. The experimental ultimate bond strengths were compared with the theoretical values as per BS 8110. The flexural behaviour of OPS concrete beams was examined by testing 9 under-reinforced prototype beams under two-point loads. The experimental flexural properties such as the bending moment, deflection and cracking characteristics were compared with the design code provisions of BS 8110 and ACI 318, and these codes gave reasonable estimates of the experimental values. Other flexural properties namely the ductility, end rotation and strain development were compared to that of other lightweight concretes. In terms of durability, the water permeability, water absorption, volume of permeable voids (VPV), sorptivity, 90-day salt ponding, cyclic wetting and drying, and rapid chloride penetration test (RCPT) of OPS concrete were investigated. These durability properties were also compared with the work of other researchers. This experimental investigation confirmed that OPS concrete performed similarly to other structural lightweight concretes. The results obtained from this investigation provided a critical understanding on the performance of OPS concrete, thereby confirming that OPS can be used as coarse aggregates for structural lightweight concrete.

ABSTRAK

KAJIAN KE ATAS KONKRIT STRUKTUR RINGAN MENGUNAKAN AGREGAT TEMPURUNG KELAPA SAWIT (OPS)

Satu penyiasatan experimen telah dijalankan ke atas konkrit struktur ringan menggunakan tempurung kelapa sawit (OPS) terbuang sebagai agregat kasar yang boleh diperbaharui. Nisbah bancuhan optimum untuk konkrit OPS yang diperolehi mempunyai nilai kejatuhan dalam lingkungan 50 hingga 70 mm, ketumpatan kering udara konkrit keras pada 28 hari sebanyak kira-kira 1965 kg/m^3 dan kekuatan mampatan pada 28 hari melebihi 28 MPa. Sifat-sifat kejuruteraan asas seperti kekuatan mampatan, kekuatan tegangan pemisahan, modulus perpecahan dan modulus keelastikan konkrit OPS telah dibandingkan dengan konkrit batu granit (konkrit berat biasa). Empat keadaan pengawetan telah digunakan untuk mengenalpasti kesannya ke atas sifat-sifat yang berkaitan dengan struktur dan ketahanlasakan konkrit OPS. Sifat ikatan struktur konkrit OPS telah ditentukan melalui ujian "pull-out" menggunakan pelbagai jenis and saiz tetulang besi, dan kajian in dijalankan sehingga 180 hari. Keputusan ujian kekuatan ikatan muktamad dibandingkan dengan nilai teoritis yang disyorkan oleh BS 8110. Sifat kelenturan konkrit OPS telah diuji melalui ujian ke atas 9 prototaip rasuk konkrit OPS bertetulang kurang pada beban dua titik. Sifat-sifat kelenturan yang diperolehi dari experimen seperti kapasiti kelenturan, ciri-ciri pembengkokan dan keretakan telah dibandingkan dengan syarat-syarat kod rekabentuk dari BS 8110 dan ACI 318, dan didapati bahawa kod-kod ini memberi anggaran nilai ujian yang agak munasabah. Sifat-sifat kelenturan lain seperti kelengkungan, peputaran hujung dan perkembangan terikan telah dibandingkan dengan konrit ringan yang lain. Dari segi ketahanlasakan seperti penusukan air, penyerapan air, liang kosong telap, "sorptivity", resapan klorida pada 90 hari perendaman garam, kitar basah dan kering, dan penusukan klorida cepat (RCPT) telah disiasati. Perbandingan prestasi ketahalasakan OPS konkrit juga telah dibuat dengan penyiasatan penyelidik-penyelidik lain. Penyiasatan ini mengesahkan bahawa konkit OPS mempunyai sifat-sifat yang serupa dengan konkrit struktur ringan yang lain. Keputusan yang diperolehi dari penyiasatan ini memberi pengertian kritikal dalam pestasi konkrit OPS dan dengan demikian, mengesahkan bahawa OPS boleh digunakan sebagai agregat kasar untuk penghasilan konkrit struktur ringan.

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CHAPTER 1

INTRODUCTION

1.1. Lightweight Concrete

The use of lightweight concrete has been gaining increased popularity in the past few decades in the construction industry. Lightweight concrete generally has a density of less than 2000 kg/m^3 and with compressive strength of more than 20 MPa (BS 8110), it is known as structural lightweight concrete. As its name implies, lightweight concrete is used to reduce the self-weight. With lower self-weights, substantial cost savings can be achieved as a result of smaller structural members, thinner sections, decreased storey height, lesser amount of reinforcing steel and lower foundation costs (Chandra & Berntsson, 2002; Pankhurst, 1993; Short & Kinniburgh, 1978). In addition, as total amount of materials to be handled is reduced, a subsequent reduction in labour costs and an increase in productivity can be expected (Neville & Brooks, 1990).

Lightweight concrete, especially those made from lightweight aggregates are most commonly used for structural purposes and has found applications in a variety of constructions worldwide such as bridges, precast members, buildings and also offshore structures construction (Chandra & Berntsson, 2002; Raithby & Lydon, 1981). In general, these lightweight concretes made from aggregates such as Leca (expanded clay), Lytag (sintered pulverised fuel ash) and Liapor (expanded shale), to name a few, are mostly utilised in the Western countries and are not extensively used in developing countries, which may be due to the limited supply and high production cost of the aggregates.

The use of lightweight concrete for structural applications is not popular in Malaysia. In Malaysia, the application of lightweight concrete is mostly limited to non-structural elements such as wall panels.

1.2. Renewable Resources for Construction Materials

Nearly 80% of the resources used today are non-renewable. Due to the scarcity of conventional raw materials, researchers are focusing more on developing construction materials with renewable resources. As a consequence, special attention is drawn towards the utilisation of solid wastes and by-products as aggregates, especially for lightweight concrete production in both developed and developing nations.

Where agriculture is widespread, the wastes generated from the agro-based industries provide a valuable alternative to the conventional concrete materials. Depending on the properties of each material, there is a possibility of incorporating these wastes either as cement replacement, fibres or aggregates in concrete. Table 1.1 further illustrates this.

Table 1.1: Different applications of agricultural waste in concrete

Application	Type of agricultural waste
Cement replacement	Palm-oil fuel ash, rice husk ash
Fibres	Rice husk, straw, bagasse (waste from sugarcane), coir (fibrous outer shell of coconut), jute fibre
Aggregates	Coconut shell, oil palm boiler clinker (OPBC), oil palm shell (OPS)

1.3. Waste Selection Criteria in Concrete Production

The most important consideration in the selection of waste for use in the concrete industry is the cost/benefit criteria. Taking the workability, strength and durability requirements of concrete into consideration, the optimum economic benefit will be achieved when the wastes meet the following criteria (Mannan, 2001; Nontananandh, 1990):

i) Locally available in plentiful amounts

ii) Low unit cost but of high quality

iii) No additional processing cost or minimum cost if processing is involved

iv) Does not cause any health hazards during handling

v) Easy to handle and store

vi) Does not cause degradation to the resulting product

1.4. Oil Palm Industry in Malaysia and Waste Generation

The African oil palm tree or scientifically known as *Elaeis guineensis* was brought to Malaysia in the early 1900s and is currently used in commercial agriculture for the production of palm oil. The Malaysian oil palm industry has seen an unprecedented growth in the last four decades to emerge as one of the major agricultural industry in the country. Today, Malaysia has become the world's largest producer and exporter of palm oil, with oil palm planted in over 4.05 million hectares of land (MPOB, 2006). Sabah is the largest oil palm planted state, with a coverage of about 1.2 million hectares (Wahid, 2006).

The oil palm yields about 18.88 tonnes/hectare of fresh fruit bunch (FFB) (MPOB, 2006). At the mills where the fresh fruit bunches (FFB) are processed and oil extraction takes place, solid residues and liquid wastes are generated. These wastes include empty fruit bunches (EFB), fibre, shell and effluent. The species of oil palm