POTENTIAL OF LIGHT WEIGHT FOAMED CONCRETE AS SUSTAINABLE STRUCTURAL MATERIAL BY OPTIMIZATION AND UTILIZATION OF WASTE MATERIALS

SUHAD M ABD

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POTENSI KONKRIT BENTUK FOAM BERKETUMPATAN RENDAH SEBAGAI BAHAN STRUKTUR KELESTARIAN MENGGUNAKAN PROSES OPTIMISASI DAN UTILISASI SISA BAHAN

SUHAD M ABD

TESIS YANG DIKEMUKAKAN UNTUK MEMPEROLEH IJAZAH
DOKTOR FALSAFAH

FAKULTI KEJURUTERAAN DAN ALAM BINA
UNIVERSITI KEBANGSAAN MALAYSIA
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DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

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ABSTRACT

This study was conducted in response to the need for improved concrete in economic and ecological manner while maintaining the existing goal toward creating sustainable building materials. Foamed concrete was investigated in this study as a lightweight building material that can be of significant importance if the strength is optimized and the cost is minimized. This work consists of three stages. The first stage include trial mixes for light weight foamed concrete (LFC).These trial mixes comprise on studying the effect of number of variables such as water to binder ratio, sand to cementitious materials ratio, types of sand and utilization of different waste materials for different densities in the range of 1200-1800 kg/m^3. Waste materials were investigated to improve economics associated with the use of LFC in construction without compromising the performance and sustainability goals. These materials were added to the mix as partial replacement of Ordinary Portland Cement with different percentages in order to determine their effects and to specify the optimum content for higher strength for each material. Trial mixes were done with silica fume 5-15 %, fly ash 20-40 % while ground granulated blast furnace slag was in range of 15-25 % by weight of cement. These mixes were tested in the laboratory for a number of performance criteria such as fresh density, dry density and compressive strength at different ages. It was found that these materials improve strength development for LFC. To get the most suitable mix for the designed LFC panels, optimization of LFC mix design was carried out in the second stage. First, optimum content for each material was specified then all these materials were used to perform mixes with densities in the range of 1200-1600 Kg/m^3. Fibers were introduced in this study to optimize the LFC mix and to improve the behaviour and properties. Polypropylene fibers and steel fibers were used in the range of 0.25-0.5% by volume of mix. Results revealed that fibers contribute to the strength of LFC in term of compression and tension. Superplasticizers (SP) were investigated with different amounts to enhance properties of LFC mix. It was found that the use of SP is crucial for LFC but with extensive care during the production process. The hardened LFCs were tested for compressive strength, splitting tensile strength and flexural strength to study the mechanical properties of LFC. In this stage, two types of curing were performed to determine the effect of curing regime on strength development. Also, Resonance frequency test was performed in this stage to calculate the dynamic modulus of elasticity. Last stage was the utilization of optimized LFC mix for the designed panels with different densities. Numbers of tests were conducted on these panels to investigate their behaviour and suitability for building construction. Based on the results obtained, light weight foamed concrete with desired density 1200-1600 Kg/m^3 and compressive strength of 15-34 MPa respectively was produced for the first time through utilization of waste materials and optimization of mix design including the use of SP and fibers. It can be concluded that this study has met its objectives via achieving the goal of sustainability and the goal of potential application of LFC to produce lightweight structural elements.

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ABSTRAK

Kajian ini dilakukan sebagai memenuhi keperluan untuk mempertingkatkan aspek keberkesanan kos dan ekologi konkrit tetapi masih mengekalkan tujuan utama kearah menjadikan bahan binaan yang lestari. Dalam kajian ini, konkrit berbusa telah dikaji sebagai bahan binaan ringan yang boleh digunakan jika kekuatannya dioptimumkan dan kosnya diminimakan. Kajian ini mengandungi tiga peringkat. Peringkat pertama adalah bancuhan cubaan untuk menghasilkan konkrit berbusa (LFC). Bancuhan cubaan ini melibatkan kajian terhadap kesan bilangan variasinya seperti nisbah air kepada bahan campuran simen, pasir kepada bahan campuran simen, jenis pasir yang digunakan dan bahan sisa yang berbeza dengan ketumpatannya dalam julat 1200–1800 kg/m^3. Bahan sisa digunakan untuk memperbaiki aspek ekonomi yang berkaitan dengan penggunaan LFC dalam pembinaan tanpa mengabaikan tahap kecekapan dan ketahanannya. Bahan ini digunakan sebagai gantian kepada Simen Portland Biasa dengan peratusan berbeza bertujuan mengenalpasti kesannya dan menentukan bahan optimum untuk kekuatan yang lebih tinggi bagi setiap bahan. Dalam kajian ini, bancuhan cubaan dijalankan dengan perkadaran wasap silika sebanyak 5-15%, abu terbang sebanyak 20-40% dan sangar relau bagas pula adalah 15-25% daripada berat simen. Campuran ini diuji di makmal untuk mengenalpasti beberapa kriteria seperti ketumpatan basah, ketumpatan kering dan kekuatan mampatan pada umur berbeza. Didapati bahawa bahan ini dapat meningkatkan tahap pembentukan kekuatan untuk LFC. Bagi mendapatkan campuran yang sesuai untuk panel LFC terubahsuai, pengoptimuman campuran LFC dilakukan dalam peringkat kedua. Pertama, kandungan optimum untuk setiap bahan telah ditentukan kemudian bahan-bahan ini digunakan untuk menghasilkan campuran dengan ketumpatan dalam 1200-1600 kg/m^3. Fiber telah digunakan dalam kajian ini untuk mengoptimumkan campuran LFC dan memperbaiki sifat dan kelakuannya. Fiber polipropylena dan fiber keluli digunakan dalam julat 0.25-0.5% daripada isipadu campuran tersebut. Keputusan ujikaji menunjukkan bahawa fiber keluli memberi impak lebih berbanding fiber polipropylena terhadap kekuatan LFC dalam mampatan dan tegangan. Superpemplastikan (SP) pula dikaji dengan jumlah yang berbeza untuk memperbaiki sifat-sifat bancuhan LFC. Didapati penggunaan SP memerlukan penjagaan sangat rapi semasa proses pembuatan. Kekerasan LFC telah diuji untuk kekuatan mampatan, kekuatan tegangan dan kekuatan lenturan bagi mengkaji sifat mekanikal LFC. Di peringkat ini, dua jenis penambahbaikan telah digunakan untuk mengkaji kesan terhadap regim pengawetan dalam pembentukan kekuatan. Ujian Resonance frequency telah juga dijalan di peringkat ini untuk mengira dinamik modulus elasticiti. Peringkat akhir adalah penggunaan campuran optimum LFC untuk panel rekabentuk dengan ketumpatan dan bilangan ujian yang berlainan dikaji pada panel tersebut untuk mengkaji sifat dan kesesuaian dalam pembinaan bangunan. Berdasarkan kepada hasil ujikaji yang dicapai, ianya boleh menghasilkan konkrit berbusa dengan ketumpatan 1200-1600 kg/m^3 dan kekuatan mampatan pada 15-34 MPa untuk kali pertama melalui penggunaan bahan sisa dan pengoptimuman rekabentuk bahan campuran termasuk penggunaan SP dan fiber. Sebagai rumusan, kajian ini telah mencapai objektifnya melalui pencapaian terhadap misi kelestarian dan potensi penggunaan LFC dalam menghasilkan struktur elemen berketumpatan rendah.

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LIST OF ABBREVIATIONS AND SYMBOLS

Slag	Ground granulated blast furnace slag
SP	Superplasticizer
LFC	Lightweight Foamed Concrete
MPa	Mega Pascal
W/mK	Watt/meter. Kelvin
PC	Portland cement
S/C	Sand to cement ratio

W/C	Water to cement ratio
W/B	Water to binder ratio
NRMC CIP	National ready mix concrete –concrete in practice
E_d	Dynamic modulus of elasticity
HRWR	High Range Water Reducers
HVFA	High volume fly ash
PFA	Pulverized fly ash
SF	Silica fume
CSF	Condensed silica fume
MK	High-reactivity metakaolin
SFRC	Steel fiber-reinforced concrete
WRAP	Waste and resources action program
RSA	Recycled and secondary aggregates
PVA	Polyvinyl alcohol fibers
MOE	Modulus of elasticity
CPDT	Chloride penetration depth test
MOR	Modulus of rupture
FRLACC	fiber-reinforced, lightweight aggregate, cellular concrete
SFRLACC	Steel fiber-reinforced, lightweight aggregate, cellular concrete
CLC	Cellular lightweight concrete
PCA	Portland cement association
GHGs	Green house gases
OPC	Ordinary portland cement
CSMA	Cementitious slag maker association
CS-H	Silicate hydrate
d_W	Unit weight of fresh concrete (Kg/m3)
$E_d./f_{28}$	Ratio of dynamic modulus of elasticity to 28 day compressive

	strength
f_{flex}	Flexural strength
f_{comp}	Compressive strength
f_{split}	Splitting tensile strength
ΔT	Temperature difference between inner (heated) and outer (ambient) surface
λ	Thermal conductivity
Q	Time rate of heat flow
V	The volume of the foamed concrete sample
M	The oven-dry mass of the foamed concrete sample
D_{dry}	Dry density of foamed concrete test specimen
w_1	The weight of sample after immerse in water till constant weight
w_0	The weight of 50°C oven dried sample
C	Cement content in (Kg)