PROPERTIES OF OIL PALM SHELL LIGHTWEIGHT AGGREGATE CONCRETE CONTAINING FLY ASH AS PARTIAL SAND REPLACEMENT

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SUPERVISOR’S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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Date : 03 August 2018
PROPERTIES OF OIL PALM SHELL
LIGHTWEIGHT AGGREGATE CONCRETE
CONTAINING FLY ASH AS
PARTIAL SAND REPLACEMENT

MUHAMMAD NAZRIN AKMAL BIN AHMAD ZAWAWI

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Master of Science

Faculty of Civil Engineering & Earth Resources
UNIVERSITI MALAYSIA PAHANG

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<tbody>
<tr>
<td>kg/m³</td>
<td>Kilogram per cubic metre</td>
</tr>
<tr>
<td>mm</td>
<td>Millimetre</td>
</tr>
<tr>
<td>MPa</td>
<td>Megapascal</td>
</tr>
<tr>
<td>%</td>
<td>Percent</td>
</tr>
<tr>
<td>&amp;</td>
<td>And</td>
</tr>
<tr>
<td>μm</td>
<td>Micrometer</td>
</tr>
<tr>
<td>°C</td>
<td>Degree Celcius</td>
</tr>
<tr>
<td>f_c</td>
<td>Compressive Strength</td>
</tr>
<tr>
<td>P</td>
<td>Maximum load applied to the specimen</td>
</tr>
<tr>
<td>N</td>
<td>Newton</td>
</tr>
<tr>
<td>A_c</td>
<td>Cross-sectional area of the specimen</td>
</tr>
<tr>
<td>mm²</td>
<td>Square millimetre</td>
</tr>
<tr>
<td>s</td>
<td>Second</td>
</tr>
<tr>
<td>f_cf</td>
<td>Breaking load</td>
</tr>
<tr>
<td>Ø</td>
<td>Diameter</td>
</tr>
<tr>
<td>N/mm²</td>
<td>Newton per square millimetre</td>
</tr>
<tr>
<td>σ_a</td>
<td>Upper loading stress</td>
</tr>
<tr>
<td>σ_b</td>
<td>Basic stress</td>
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<tr>
<td>ϵ_a</td>
<td>Mean strain under the upper loading stress</td>
</tr>
<tr>
<td>ϵ_b</td>
<td>Mean strain under basic stress</td>
</tr>
<tr>
<td>σ_m</td>
<td>Average compressive strength of concrete cured in water</td>
</tr>
<tr>
<td>σ_s</td>
<td>Average compressive strength of concrete cured in Na₂SO₄</td>
</tr>
<tr>
<td>E_c</td>
<td>Elasticity in compression</td>
</tr>
<tr>
<td>m₁</td>
<td>Mass of specimens before immersion</td>
</tr>
<tr>
<td>m₂</td>
<td>Mass of specimens after immersion</td>
</tr>
<tr>
<td>±</td>
<td>Plus-minus</td>
</tr>
<tr>
<td>T</td>
<td>Splitting tensile strength</td>
</tr>
<tr>
<td>d</td>
<td>Diameter</td>
</tr>
<tr>
<td>l</td>
<td>Length</td>
</tr>
<tr>
<td>kg</td>
<td>Kilogram</td>
</tr>
<tr>
<td>W/mK</td>
<td>Watts per meter-Kelvin</td>
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### LIST OF ABBREVIATIONS

<table>
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<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>ACI</td>
<td>American Concrete Institute</td>
</tr>
<tr>
<td>Al</td>
<td>Aluminium</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>Aluminium oxide</td>
</tr>
<tr>
<td>ASTM</td>
<td>American Society for Testing and Materials</td>
</tr>
<tr>
<td>BET</td>
<td>Brunauer, Emmett and Teller</td>
</tr>
<tr>
<td>BS</td>
<td>British Standard</td>
</tr>
<tr>
<td>BS EN</td>
<td>British Standard European Norm</td>
</tr>
<tr>
<td>Ca</td>
<td>Calcium</td>
</tr>
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<td>CaCO₃</td>
<td>Calcium carbonate</td>
</tr>
<tr>
<td>CaO</td>
<td>Calcium oxide</td>
</tr>
<tr>
<td>Ca(OH)₂</td>
<td>Calcium hydroxide</td>
</tr>
<tr>
<td>CIDB</td>
<td>Construction Industry Development Board</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>C-S-H</td>
<td>Calcium silicate hydrate</td>
</tr>
<tr>
<td>CSR</td>
<td>Compressive strength reduction</td>
</tr>
<tr>
<td>CuO</td>
<td>Copper</td>
</tr>
<tr>
<td>C₃A</td>
<td>Tricalcium aluminate</td>
</tr>
<tr>
<td>DDIs</td>
<td>Domestic direct investments</td>
</tr>
<tr>
<td>EE</td>
<td>Energy efficiency</td>
</tr>
<tr>
<td>EFP</td>
<td>Empty fruit bunch</td>
</tr>
<tr>
<td>FA</td>
<td>Fly ash</td>
</tr>
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<td>FDI</td>
<td>Domestic direct investments</td>
</tr>
<tr>
<td>Fe</td>
<td>Iron</td>
</tr>
<tr>
<td>FELCRA</td>
<td>Federal Land Consolidation and Rehabilitation Authority</td>
</tr>
<tr>
<td>FELDA</td>
<td>Federal Land Development Authority</td>
</tr>
<tr>
<td>FESEM</td>
<td>Field Emission Scanning Electron Microscope</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>Iron oxide</td>
</tr>
<tr>
<td>FM</td>
<td>Fineness modulus</td>
</tr>
<tr>
<td>GBI</td>
<td>Green Building Index</td>
</tr>
<tr>
<td>GDP</td>
<td>Gross domestic product</td>
</tr>
<tr>
<td>GTFS</td>
<td>Green Technology Financing Scheme</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td>H₂O</td>
<td>Water</td>
</tr>
<tr>
<td>IOI</td>
<td>Industrial Oxygen Incorporated</td>
</tr>
<tr>
<td>K</td>
<td>Potassium</td>
</tr>
<tr>
<td>KeTTHA</td>
<td>Kementerian Tenaga Teknologi Hijau Dan Air</td>
</tr>
<tr>
<td>K₂O</td>
<td>Potassium oxide</td>
</tr>
<tr>
<td>LOI</td>
<td>Loss of ignition</td>
</tr>
<tr>
<td>LWA</td>
<td>Lightweight aggregate</td>
</tr>
<tr>
<td>LWAC</td>
<td>Lightweight aggregate concrete</td>
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<tr>
<td>LWC</td>
<td>Lightweight concrete</td>
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<tr>
<td>MgO</td>
<td>Magnesium oxide</td>
</tr>
<tr>
<td>MnO</td>
<td>Manganese</td>
</tr>
<tr>
<td>MPOB</td>
<td>Malaysian Palm Oil Board</td>
</tr>
<tr>
<td>MS</td>
<td>Malaysian Standard</td>
</tr>
<tr>
<td>Na</td>
<td>Sodium</td>
</tr>
<tr>
<td>NRMCA</td>
<td>National Ready Mix Concrete Association</td>
</tr>
<tr>
<td>OPC</td>
<td>Ordinary Portland Cement</td>
</tr>
<tr>
<td>OPS</td>
<td>Oil palm shell</td>
</tr>
<tr>
<td>PAIP</td>
<td>Pengurusan Air Pahang Berhad</td>
</tr>
<tr>
<td>PKC</td>
<td>Palm kernel cake</td>
</tr>
<tr>
<td>POC</td>
<td>Palm oil clinker</td>
</tr>
<tr>
<td>POFA</td>
<td>Palm oil fuel ash</td>
</tr>
<tr>
<td>POME</td>
<td>Palm oil mill effluent</td>
</tr>
<tr>
<td>PV</td>
<td>Solar photovoltaic</td>
</tr>
<tr>
<td>RE</td>
<td>Renewable energy</td>
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<tr>
<td>RILEM</td>
<td>International Union of Laboratories and Experts in Construction Materials, Systems, and Structures</td>
</tr>
<tr>
<td>RM</td>
<td>Ringgit Malaysia</td>
</tr>
<tr>
<td>Sdn Bhd</td>
<td>Sendirian Berhad</td>
</tr>
<tr>
<td>SEM</td>
<td>Scanning Electron Microscopy</td>
</tr>
<tr>
<td>Si</td>
<td>Silicon</td>
</tr>
<tr>
<td>SiO₂</td>
<td>Silicon dioxide</td>
</tr>
<tr>
<td>SMEs</td>
<td>Small and medium enterprises</td>
</tr>
<tr>
<td>SMIs</td>
<td>Small- and medium-sized industries</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>--------------</td>
<td>------------------------------------</td>
</tr>
<tr>
<td>SO$_3$</td>
<td>Sulphur trioxide</td>
</tr>
<tr>
<td>SP</td>
<td>Superplasticizer</td>
</tr>
<tr>
<td>SSD</td>
<td>Saturated surface dry</td>
</tr>
<tr>
<td>Ti</td>
<td>Titanium</td>
</tr>
<tr>
<td>UK</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>UNEP</td>
<td>United Nations Environment Programme</td>
</tr>
<tr>
<td>w/c</td>
<td>Water to cement ratio</td>
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</tbody>
</table>
Industri minyak kelapa sawit yang berkembang telah meningkatkan bahan buangan kelapa sawit yang dikenali sebagai tempurung kelapa sawit (OPS) dan lebih daripada 4 juta tan dibuang di tapak pelupusan setiap tahun. Pada masa yang sama, kira-kira 350 juta tan abu terbang (FA) yang merupakan bahan buangan loji arang batu dihasilkan setiap tahun. Disebabkan pengeluaran sisa yang besar, ia memberi kesan yang buruk kepada persekitaran. Pada masa yang sama, kemajuan industri pembinaan telah meningkatan aktiviti perlombongan pasir sungai. Perlombongan yang tidak terkawal menimbulkan kesan buruk terhadap alam sekitar seperti pendalaman sungai dan hakisan tebing sungai. Keperluan bahan pembinaan dan isu masalah alam sekitar yang semakin meningkat disebabkan bahan buangan industri minyak sawit telah mencetuskan penyelidikan ke arah menghasilkan teknologi baru hijau seperti konkrit ringan. Kajian sebelum ini pernah mengintegrasikan OPS bersama abu terbang kelapa sawit (POFA) serta abu terbang (FA) sebagai bahan gentian separa simen. Walaubagaimanapun, penggantian abu terbang (FA) sebagai pengganti pasir dalam penghasilan konkrit agregat ringan tempurung kelapa sawit (OPS LWAC) sepertinya belum diikuti. Justeru, penyelidikan ini memberi tumpuan kepada penggunaan FA sebagai bahan pengganti pasir sungai dalam penghasilan OPS LWAC. Abu terbang (FA) digunakan sebagai pengganti pasir separa dalam pengeluaran konkrit agregat ringan (LWAC) bagi mengurangkan penggunaan pasir dalam pembinaan, mengurangkan pencemaran dan jumlah sisa yang dilupuskan. Sementara itu, penggunaan OPS dalam konkrit agregat ringan (LWAC) sebagai pengganti agregat kasar akan membantu mengekalkan sumber semula jadi seperti granit dan batu kapur. OPS LWAC dengan 100% pasir sungai digunakan sebagai spesimen kawalan. Kemudian, satu siri campuran OPS LWAC yang dicampur dengan FA dengan peratusan seperti 10%, 20%, 30% dan 40% telah disediakan. OPS pula digunakan sebagai aggregat kasar yang menggantikan 100% batu granit. Campuran terbaik telah dipilih dan digunakan untuk memuaskan sifat mekanik dan ketahanan OPS LWAC. Keset pengawetan iaitu pengawetan air, udara dan pengawetan air awal terhadap sifat mekanik OPS LWAC yang mengandungi FA ditutup dikaji. Selain itu, ujian lain yang dijalankan ialah rintangan sulfa, penyerapan air dan karbonasi. Semua spesimen diuji sehingga 9 bulan. OPS LWAC yang mengandungi 10% FA menunjukkan prestasi terbaik antara semua peratusan dari segi mekanikal dan ketahanan. Penggunaan abu terbang (FA) yang sesuai meningkatkan jumlah C-S-H yang terhasil daripada proses penghidratan dan pozzolanik dan mengisi kekosongan struktur dalam konkrit menjadikannya padat dan kuat. Penggantian 40% FA memberi kesan terburuk kepada OPS LWAC dari segi sifat mekanikal dan ketahanan. Penemuan menunjukkan bahawa pengawetan air adalah kaedah pengawetan yang terbaik untuk memastikan prestasi yang lebih baik terhadap kekuatan mampatan, lenturan, keanjaran dan kekuatan tangga OPS LWAC yang mengandungi FA diikuti dengan pengawetan air awal dan pengawetan udara. Juga, OPS LWAC dengan 10% FA memperbaiki ketahanan yang lebih tinggi berbanding spesimen kawalan serta lain-lain campuran apabila diserang sulfat. OPS LWAC dengan 10% FA mempunyai prestasi rintangan yang lebih baik dalam sulfat kerana tindak balas pozzolanik yang mengurangkan kuantiti kalsium hidroksida yang mudah diserang oleh persekitaran yang agresif. Tiada karbonasi dikesan pada spesimen yang diawet menggunakan air serta pengawetan air awal kecuali specimen yang diawet dalam udara persekitaran. Pengawetan air menggalakkan proses penghidratan dan reaksi pozzolanik yang meningkatkan struktur dalam OPS LWAC dengan FA menyebabkan ia memperbaiki kadar penyerapan yang lebih rendah berbanding kaedah pengawetan yang lain.
ABSTRACT

The steady growth of the palm oil industry has led to the generation of the palm oil mill by-product known as oil palm shell (OPS) amounting more than 4 million tonnes annually which are dumped in the landfill. At the same time, the annual world production of fly ash (FA) which is a by-product of coal-fired electric power plants is approximately 350 million tonnes. Due to large production, these waste are also dumped that in turn, significantly affects the surrounding environment. On the other hand, the growing construction industry has led towards the increase in river sand mining activities. However, unregulated mining by the authorities may pose adverse impact towards the environment as it lowers the stream bottom, which in turn may lead to bank erosion. The growing demand for construction material and environmental issues created from the by-products of palm oil industry as well as coal industry have initiated research towards producing a new lightweight concrete. OPS has been previously utilized with POFA and FA as partial cement replacement. However, it is non-trivial to mention that study on the integration of fly ash (FA) as sand replacement in OPS LWAC has yet been reported. Thus, this research focuses on investigating the properties of Oil Palm Shell Lightweight Aggregate Concrete (OPS LWAC) containing various percentage of FA as partial sand replacement. Fly Ash (FA) is utilized as partial sand replacement in the production of Lightweight Aggregate Concrete (LWAC) in order to reduce sand usage in construction, reduce pollutions as well as the amount of waste disposed. Meanwhile, the use of OPS in lightweight aggregate concrete (LWAC) as a coarse aggregate replacement will help to preserve natural resources such as granite and limestone. The plain OPS LWAC content with 100% sand was used as a control mix. Then, a series of OPS LWAC mixes with FA of various percentages such as 10%, 20%, 30% and 40% were prepared. The OPS was utilized as coarse aggregate with 100% replacement throughout the research. The best mix acquired from the trial mixes were used to investigate the mechanical and durability properties of OPS LWAC. The effect of curing namely water curing, air curing and initial water curing regimes on mechanical properties aspect of OPS LWAC containing FA has been determined. Furthermore, other durability properties tests have been carried out namely sulphate resistance test, water absorption and carbonation. All specimens were tested until 9 months. OPS LWAC containing 10% FA performs the best amongst all percentages in terms of mechanical and durability properties. The inclusion of a suitable amount of fly ash produces larger amount of C-S-H gel from both hydration and pozzolanic reaction which fills in the void of concrete internal structure making the concrete denser and stronger. It was demonstrated that 40% of FA replacement provided the worse effect to the OPS LWAC in term of mechanical and durability properties. The findings show that water curing is the best curing method to ensure better performance on compressive strength, flexural strength, modulus of elasticity and splitting tensile strength of OPS LWAC containing FA followed by initial water curing and air curing. Also, OPS LWAC with 10% FA exhibit higher durability compared to control specimens and others mixes when subjected to sulphate attack. OPS LWAC with 10% FA has better performance in sulphate solutions since the pozzolanic reactions reduce the quantity of calcium hydroxide which is vulnerable towards aggressive environment. No carbonation rate was detected for specimens subjected to water curing and initial water curing except for air curing. Water curing promotes better hydration process and pozzolanic reaction that improves the internal structure of OPS LWAC containing FA causing it to exhibit lower absorption value compared to other curing methods.
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