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Response of oil palm shell concrete slabs subjected to quasi-static and blast loads

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HIGHLIGHTS

- 10 concrete panels were tested for quasi-static and blast testes.
- OPSC panels' superior performance in blast resistance was observed.
- OPS has fibre and it withstood 10 kg TNT and proved blast resistant concrete.
- OPSC subjected to 10 kg TNT had no fragments, however NC had shrapnel and damaged.
- Use of 3% fibres produced non-uniform mix and resulted in fibre pull-out failure.

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ABSTRACT

A series of quasi-static and blast tests was conducted to investigate resistance capacity of concrete slabs in which conventional crushed granite aggregates were wholly replaced with oil palm shell (OPS) as a coarse aggregate. A control specimen using Normal Concrete (NC) using conventional aggregate of similar strength was also prepared and tested for comparison. Two types of OPS concrete (OPSC) slabs were developed-with and without steel fibres (SF) and tested. LVDTs, pressure transducers and accelerometers were used to record data of response of the slabs subjected to quasi-static load and blast loads of 1, 5 and 10 kg TNT. The recorded data were then analysed and compared and conclusions were made on the effectiveness of OPS as a coarse aggregate. It has been found that OPSC outperformed NC slab when subjected to 10 kg TNT as the ductile OPSC panel was intact and had no shrapnels. Through the ductility behaviour of OPSC, it exhibited multiple cracks and the impact resistance of OPS through its energy absorption due to fibrous content within OPS itself was visible both in crack pattern and in its propagation. Though OPS is of organic nature, its resistance to blast waves was observed as the huge fire ball created due to blast had no or little effect on the OPSC panels. The OPS Fibre Reinforced Concrete (OPSFRC) also exhibited blast resistance characteristics, but uneven distribution of fibres and harsh mix with 3% of steel fibres resulted in larger crack width and fibre pull-out failure. Overall, the behaviour of OPSC in blast resistance characteristics is noteworthy and further tests are required to envisage the use of appropriate fibre content in OPSC.

1. Introduction

During the last two decades, the world had witnessed dramatic rise in bomb attacks and there is growing trend of terrorist activities to blow up vital infrastructures and these threats are mainly linked with bombing. The protection of structures against terrorist attacks, explosions, and accidents is paramount task and in order to address this major issue research initiatives and significant changes in design are gaining prominence. In order to protect civilians and buildings against blast loading and other accidental explosions, there is a need for concrete structures to have resistance against blast waves and impacts. Furthermore, such structures should have a certain ductility performance to ensure that even in the event of blast loading, there is sufficient warning and time for civilians and occupants to escape from the buildings. Some of

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the current research in the development on blast resistance concrete includes ultra-high performance fibre reinforced concrete [1], reactive powder concrete [2], ultra-high performance fibre reinforced cementitious composites (UHPFRCCs), anti-blast water wall, aluminum foam or steel sheets, concrete-filled double-skin tubes (CFDST) [3–7]. However, considering that these high-strength materials are expensive and are usually brittle upon failure, in which addition of fibres are required, it will be appealing to have a more inherently energy-absorbing material which would also be of lower cost. In most of the blast resistant concrete or related materials, the desired characteristic is the ductility of the material that enables progressive collapse [8]. Though normal weight concrete with fibres has been traditionally used in the development of high strength concretes, investigation on alternate materials is ongoing. One of the most crucial components in blast-resistance structures is the selection of material in the concrete itself. Materials with good shock-absorbing characteristics have the potential to be utilized for improved ductility when subjected to impact forces and hence the enhanced blast resistance characteristics.

Thus, in addition to focussing on enhancing the ductility of the concrete through the use of fibres in high strength concrete, the use of appropriate aggregate that could absorb the energy during blast loading should be given due consideration. Since aggregates occupy about 50–75% of concrete volume, the selection of coarse aggregate which is one of the principal constituent materials, has to be effective in energy absorption and in turn to enhance the ductility of the concrete. One of the natural coarse aggregates from palm oil industry found to have 4–5 times higher aggregate impact resistance is oil palm shells (OPS). Since 1984 research works on utilizing this industrial waste material had led to many research works that included mechanical, structural and functional properties of Oil Shell Concrete (OPSC) [9–12]. Malaysia is the second largest producer of palm oil in the world and during the production of palm oil, the palm oil industries across Malaysia generates about 4 million tons of OPS annually as a waste material [13]. Fig. 1 shows OPS in factory yard with diverse shapes and fibrous convex surface.

Another significant reasoning behind the use of OPS as an alternative for coarse aggregate in manufacturing concrete is due to a desirable solution to deteriorating natural resources caused by using granite aggregate and environmental pollution due to stockpile of OPS in the factory yards in open-air [14–17]. Further advantage on the use of OPSC is its low density as lightweight concrete of density below 2000 kg/m^3 could be produced; due to the low bulk density of OPS, OPSC has a density 20–25% lower than conventional concrete about 1900 kg/m^3 which makes it lightweight concrete (LWC) [14,15]. As known LWC has several advantages over conventional concrete such as savings on reinforcement, formwork, scaffolding, foundation cost, etc. due to reduction of self-weight of structures and better sound absorption, frost resistance and anti-condensation properties [18]. LWC has significantly low fracture toughness and tensile strength which makes it a brittle material. Hence recent research has focused on adding fibres into LWC so as to get better mechanical properties as well as to improve the ductility and flexural toughness [19,20,12].

As mentioned OPS, an agricultural by-product, is known to exhibit lower aggregate impact value (AIV) than normal granite aggregates, and this indicates good shock-absorbing properties of the OPS [21,22]. The AIV value of OPS was reported to be in the range of 3–4% compared to about 16% for crushed granite aggregate [21,23–25]. In lab-scale impact testing on panel specimens, it was found that concrete prepared with OPS lightweight aggregate had better impact resistance compared to high strength concrete and this was attributed to the lower AIV value and shape of the OPS aggregates [26]. In addition, the greater ductile behaviour of OPSC compared to conventional concrete was observed by researchers [27] and the major contributing factor of the ductility of OPSC is the low modulus of elasticity (MOE) of the resulting concrete. Alengaram et al. [27] and Teo et al. [24] studied the shear and flexural behaviours of reinforced OPSC beams and concluded that the design equations in BS8110 can be used for prediction of the moment capacity of OPSC beams with up to certain amount of reinforcement ratio and the deflections and the crack widths are within the allowable limits and durability requirements given by BS8110.

Similarly, Onoue et al. [28] investigated the use of pumice aggregate concrete as buffer material for impact protection and found improved impact resistance of such concrete. In the study, the improved shock-absorbing performance of the pumice concrete was also credited to the lower MOE of the pumice concrete. Bischoff et al. [29] also echoed the suggestion of better shock-absorbing ability of lightweight concrete from investigations carried out on polystyrene aggregate concrete. According to the outcome of the research, the polystyrene aggregate concrete had improved impact resistance due to its low crushing strength and high degree of deformability or low MOE.

The addition of steel fibres is known to enhance the ductility performance of concrete, and this is of particular interest for structures subjected to blast and impact forces. While the improvement in blast and impact resistances of steel fibre reinforced normal weight concrete are known, there is no literature on blast resistant characteristic of steel fibre reinforced OPSC. Mo et al. [30] studied the effect of steel fibres on characteristics of OPSC and concluded that the effect of fibres in arresting the cracks and their propagation enhances the mechanical properties of OPSC such as compressive strength, splitting tensile strength and flexural tensile

Fig. 1. Oil palm shells (OPS).