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# Mechanical properties of lightweight mortar modified with oil palm fruit fibre and tire crumb

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## HIGHLIGHTS

- Mechanical properties of mortar with tire crumb replacement and OPFF addition.
- We examine changes of tire crumb from 0% to 40% replacement of fine aggregates.
- We examine changes of addition of OPFF from 1% to 1.5%.
- Increase compressive, split tensile and flexural strengths when 0.5% OPFF added.

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ABSTRACT

This research use oil palm fruit fibre (OPFF) as a greener and more cost-effective approach to improve the tire crumb mortar composite strengths. The mechanical properties of tire crumb and oil palm fruit fibre lightweight mortar with addition of 0%, 0.5%, 1% and 1.5% OPFF and tire-crumb replacement of 0–40% by volume of aggregate were studied. The composite mixtures were subjected to the compression, split tensile and flexural tests. The addition of 0.5% OPFF to the composite was found to improve the compressive strength, split tensile strength and flexural strength of the mortar composites.



## 1. Introduction

The benefits derived from the incorporation of lightweight aggregate in concrete in the 20th century have led to the quest for additional lightweight aggregate materials due to their low density. Lightweight aggregate concrete (LWAC) material has a low density and will subsequently reduce the total dead weight on lower structural members, which reduces construction time and overall construction cost [1]. LWAC has been used for over 2000 years, and its use has been widespread for the past 90 years. Its structural efficacy has contributed to sustainable development by optimisation of design and construction effectiveness, increased durability of the products during their service life and reduced transportation requirements [2]. Narayanan and Ramamurthy [3] indicated that by employing suitable methods, lightweight concrete with a wide range of densities could be produced, which would offer flexibility in the development of composite products for numerous civil engineering applications.

Several attempts have been made to incorporate waste tire particles in the form of coarse, fine and a combination of both in concretes and mortars for the past two decades and recently in the form of ash. Improved efficiency in the performance of the composite has been recorded, especially in terms of density, thermal conductivity, electrical resistivity, ductility, etc. The substitution of waste tire particles in concrete has shown good potential in terms of toughness, ductility and energy dissipation capacity [4]. Khatib and Bayomy [5] reported that an increase in the waste tire content could lower the density of concrete to as low as 75% of the normal concrete weight. However, a reduction in the mechanical properties of waste-tire-incorporated concretes has been reported by many researchers. Reductions in compressive strength, split tensile strength, flexural strength and elastic modulus have been reported by [5–14].

## 2. Research background

The decrease in the mechanical properties of waste-tire-incorporated concrete called for the need to recoup these losses.

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There have been on-going efforts to reverse or at least mitigate the effects of the losses in mechanical properties of the resulting concrete. These have included pre-treating the waste tire particles with chemicals, cement and additives. Pelisser et al. [15] investigated the effect of waste-tire concrete formulated by pre-treating the tire waste with sodium hydroxide (1 M NaOH) and silica fume at 15% along with lignosulphonate admixture alkaline activation and silica fume addition to improve the mechanical properties of the concrete. Chou et al. [16] studied the influence of treating waste tire aggregate with organic sulphur compounds from a petroleum refining factory to modify the surface texture of waste tire aggregate. Colom et al. [17] used tire waste treated with various mineral acids, namely $H_2SO_4$, $HNO_3$ and $HClO_4$. These were used in high-density polyethylene (HDPE) tire composites.

Segre and Joekes [18] attempted to improve the properties of waste-tire-incorporated concrete by pre-treating the waste tire particles with saturated NaOH aqueous solutions. In 1998, Li et al. [9] investigated the effect of waste tire pre-treated with cement paste and Methocel cellulose ethers in concrete. Lee et al. [19] studied tire-added latex concrete (TALC) by incorporating waste-tire particles in the concrete, and in 1996, Biel and Lee [20] investigated the effect of Portland cement or magnesium oxychloride cement as binders in waste-tire-incorporated concrete. Some of these pre-treatment techniques yield substantial results; however, the chemicals and additives used are quite expensive and could increase the overall cost of the resulting concrete or mortar produced. This paper presents a greener and cost-effective alternative approach by employing oil palm fruit fibre (OPFF) in the matrix, which could transfer its strength to the composite to improve the mechanical performance of the composite. The OPFF is fibre that is derived from oil palm fruit bunches that are disposed of in landfills after the extraction of crude oil palm in the refineries. These are obtained free of charge at present.

An incorporation of waste tire particles in concrete and mortars had reported to produce low mechanical properties of the composite mixtures. Thus, chemicals and additives are introduced to improve the strengths but the mixture become more expensive. This research substitute chemicals with oil palm fruit fibre (OPFF) as a greener and more cost effective approach to improve the composite strengths. The mortar is studied as fulfilling the potential of real applications such as bricks and precast lightweight wall.

## 3. Materials and methods

### 3.1. Materials

The fine aggregate used in this experiment consisted mainly of stone dust with a maximum particle size passing a 4.75 mm sieve. This aggregate was supplied from quarries around Malaysia and conforms to ASTM C33 (2004) [21]. The specific gravity, density, fineness modulus and the absorption of the fine aggregate are 2.63, 1702 kg/m$^3$, 0.9 and 3%, respectively.

The tire crumb aggregate used in this experiment was supplied by Arajaya Enterprise Sdn. Bhd Malaysia and was graded in the same particle size distribution as the quarry dust passing sieve size 4.75 mm to enable convenient volumetric substitution. The tire crumb particles were observed to be clean as supplied, and the compacted density and fineness modulus were measured to be 589 kg/m$^3$ and 0.9, respectively.

The oil palm fruit fibre was obtained free of charge from Seri Ulu Langat Palm Oil Mill Sdn. Bhd, Dengkil, Malaysia. The fibre was washed with water in a concrete mixer by allowing the mixer to roll continuously while changing the water until clean and colourless water was observed in the mixer. The fibre was then dried and cut into 3–5 cm lengths and stored for use in the experiment. Fig. 1 shows the oil palm fruit bunch and oil palm fruit fibre as received from the factory and OPFF after washing before use in this study.

The mortar specimens were prepared from locally available Portland cement Type II conforming to (ASTM C150, Type II) [22], and pipe-borne potable water available in the Universiti Putra Malaysia was used for all of the mixtures and curing.

### 3.2. Mix proportions

Twenty mix designs were prepared in this research work, and volumetric substitution of fine aggregate with tire crumb was carried out at 0%, 10%, 20%, 30% and 40% using a water–cement ratio of 0.485 and cement-to-aggregate ratio of 1:2.75 in accordance with the requirement of ASTM C109-05 [23] for hydraulic cement mortars. The oil palm fruit fibre was added to the mixtures at 0.5%, 1% and 1.5% by mass of the cement content except the control, which does not contain the fibre. The details of the mix proportions are shown in Table 1. Note that the water content stated in Table 1 is including 3% water absorption from fine aggregates.

### 3.3. Mixing procedure

The mixing was carried out by placing the fine aggregate, cement and the tire crumb aggregate in the bowl mixer and allowing it to mix for 2 min. One-third (1/3) of the water and the OPFF were added and allowed to mix for an additional 2 min. The remaining water was added for the final mixing until a consistent mix was achieved throughout the mass. This procedure was used to prevent the balling effect experienced using the conventional approach.

### 3.4. Test program

The workability test for the various mixes was carried out in accordance with the standard test method for the flow of hydraulic cement mortar specified in ASTM C1437 [24]. Flow table test apparatus used in this work is in line with the specification of ASTM C230 [25].

The density and absorption test by immersion was conducted in this experiment in accordance with ASTM C642 [26] by producing and curing 60 mortar specimens of size 50 × 50 × 50 mm.

The compressive strength test was conducted by using 180 cubes of size 50 × 50 × 50 mm produced from hydraulic cement mortar in accordance with the requirement of ASTM C109 [23]. The cube specimens were water cured and tested in compression using a universal testing machine for curing periods of 3, 7 and 28-days under similar conditions at a loading rate of 0.75 kN/s.

The split tensile test was conducted by using the principles and procedure outlined in ASTM C 496 [27], and the specimens were water cured for 7 and 28-days before testing. Cylindrical samples 100 × 200 mm in size were produced and tested using a universal testing machine at a loading rate of 2.35 kN/s until failure.

The flexural test was conducted on 40 test specimens 40 × 40 × 160 mm in size supported at 100 mm centre-to-centre in accordance with the requirement of ASTM C348 [28], referred to as the third point method and tested at deflection rate of 0.5 mm/min until failure. The machine recorded automatically the load displacement readings.

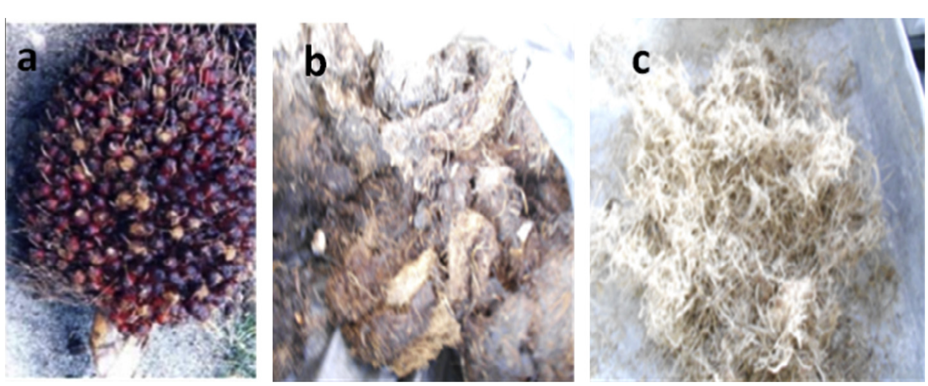


**Fig. 1.** (a) Palm oil fruit bunch, (b) OPFF as obtained from factory and (c) OPFF after washing.