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The feasibility of improving impact resistance and strength properties of sustainable concrete composites by adding waste metalized plastic fibres

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HIGHLIGHTS

- Waste metalized plastic (WMP) fibres and POFA were used in the production of sustainable concrete.
- Impact resistance and strength properties of concrete were evaluated.
- The combined effect of WMP fibres and POFA in enhancing the impact resistance of concrete is highlighted.
- WMP fibres significantly developed the energy absorption and ductility of concrete.

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ABSTRACT

Waste plastic results in waste discarding disaster and consequently cause significant harms to the environment. The utilisation of industrial wastes in the production of sustainable concrete has attracted much consideration in recent years because of the low-cost of waste materials along with saving a significant place for landfill purposes and also enhance the performance of concrete. In this paper, the feasibility of waste metalized plastic (WMP) fibres and palm oil fuel ash (POFA) in the production of concrete composites was investigated by assessing the impact resistance and strength properties. Six concrete mixes containing WMP fibres varying from 0 to 1.25% with a length of 20 mm were made of ordinary Portland cement (OPC). A different six concrete mixtures with the same fibre content were made, where 20% POFA substituted OPC. The combination of WMP fibres and POFA reduced the slump values of concrete mixes. The inclusion of WMP fibres to OPC and POFA concrete mixes decreased the compressive strength. However, at the curing period of 91 days, the POFA-based mixes obtained higher compressive strength values than those of OPC-based mixtures. The positive interaction among WMP fibres and POFA consequently improved the impact resistance, flexural and splitting tensile strengths, thereby developing the energy absorption capacity and concrete ductility. It is concluded that the utilisation of WMP fibres and POFA in the production of sustainable concrete composites is potential to enhance the impact resistance and strength properties of concrete components that can be used in structural and non-structural applications.

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1. Introduction

In the last decades, through the growing awareness regarding the environment, lack of landfill area and owing to its ever-growing price, utilisation of wastes has become a desirable alternative solution to discarding. Irregular consumption of raw resources, great quantity manufacture of pre- and post-consumer waste materials and environmental pollutions need achieving novel alternative ways for sustainable development. The interest in using alternative materials such as waste materials in construction industries has grown incessantly [1,2]. This is in line with fundamental environmental strategies; prevention of waste, recycling of waste materials, escaping landfill, energy regaining from waste, and saving raw materials. While substitute resources are used in different fields of application, the technical aspects, financial features, and environmental concerns are also essential to be addressed and well-adjusted [3]. Consequently, Yin et al. [4]

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suggested that this makes slight sense to reutilise the abundant and low-cost material in an application not lighting the technical or environmental standards; a technically and environmentally complying application utilising waste materials, but with a higher cost than the traditional solution, also is not beneficial.

Due to the high rigidity and low tensile strength of plain concrete, it considers as brittle materials. There are numerous concrete components and structures exposed to impact loads, for instance, hydraulic structures, wall panels, bridge decks, airport pavements, highway paving and industrial floors. Therefore, higher resistance to impact loads and load carrying capacity are required in this kind of applications. Further constituents are necessary to improve these particular properties of concrete where these necessities are vital [5,6]. In regards to the said matter, Caggiano et al. [7], Abdollahnejad et al. [8], and Mastali and Dalvand [9] reported that fibre reinforced cementitious composites have the ability to address the brittleness of concrete.

Concrete composite is a mixture that comprises binders, fine and coarse aggregates, and small discontinuous fibres that are arbitrarily dispersed in the concrete mixture. These short fibres significantly enhance impact resistance, ductility, and energy absorption of concrete in addition to higher values of splitting tensile and flexural strengths [10–12]. Different kinds of short fibres, either metallic or polymeric, are usually applied for reinforcement of concrete for their advantages [13,14]. Among others, the most popular types of fibres mixed into concrete are glass, steel, polypropylene (PP), waste fibre from pre- and post-consumer, and natural fibres. Utilization of post-consumer waste plastics such as polyethylene terephthalate (PET) in the production of concrete has revealed possibility towards the sustainable and green construction with a benefit of the harmless alternative of waste plastics disposal [15–18]. In their studies, Mastali et al. [19] and Foti [20] worked on the reinforced concrete with recycled glass fibres and waste PET fibres. They found that adding these waste fibres could have significant effects on development of strength and post-cracking performance of concrete composites. In addition, Mastali and Dalvand [21], Caggiano et al. [22], Aghaee et al. [23] and Martinelli et al. [24] also studied the feasibility of recycled steel fibres. They point out the utilization of recycled steel fibres in concrete could significantly enhance the ductility. Though, the waste metalized plastics are not reprocessed efficiently and ignored thus far for their potential and sustainable use in the production of green concrete.

In the past 50 years, the plastic production has raised massively globally, and various types and forms of plastics have come to be a vital part of our modern lifestyle. It has significantly contributed to the generation of wastes related to plastics. Polymeric-based plastics are extensively used in more or less all fields, mainly in food packaging, electronics and electrical, automotive, agriculture, and other different industries [25,26]. According to Gu and Ozbakkaloglu [27], and Sharma and Bansal [28], the overall manufacture of plastics is given an account to have raised to 288 million tons in 2012, worldwide. Approximately half of this products was a one-use consumer, which caused critically to the generation of different sorts of plastic wastes.

Polymers are industrialised to supply the high demand for plastic products. The high demand for various types of plastic by packaging industries reveals that the ideas of recycling, reduction, and reprocess are yet to be attained by developing countries [29]. Growth in littering and discarding of different kinds of plastic particularly in the urban areas demonstrates limitations in the disposal of post-consumer waste plastics. Therefore, mismanage of waste plastics leads to severe environmental concerns such as human's health hazards, effects on animal's life, water, air pollutions, and soil impurities. However, most of these waste plastics have potential to recycle and reuse by chemical or thermal processes, but not all waste plastics appropriate for this classification [30,31]. Amongst all, waste metalized plastics used by food packaging industries are unfit for reprocessing and reuse. Currently, the main ways of disposal of such a considerable amount of waste plastics are limited to incineration and landfill [32]. Therefore, reliable and sustainable discarding substitutions to the existing methods have become an essential.

Metalized plastic films are made of a polymer which coated with a thin sheet of metal, typically aluminium. These films offer the glossy metallic appearance of an aluminium foil at a lower cost and mass. Metalized plastic films are extensively used for food packaging, particular applications such as insulation and electronics, and also for decorative purposes [33]. Among all, aluminium is the popular metal applied for coating, however, other metals, for instance, nickel or chromium are also used. This coating will not disappear or fade along with time, and it is considerably thinner than a metal foil could be made, which is about 0.5 μm. Polyethylene terephthalate (PET) and polypropylene (PP) are the most common polymeric films which are used for metallization. The purpose of the film coating is to reduce the penetrability to liquids, air, and light [34,35]. The advantages of using these waste metalized films include the capability to be heat sealed, higher toughness, lower density and lower cost as compared to an aluminium foil. Therefore, it offers metalized films some benefits over other types of waste plastics. In this research work waste metalized plastic films used for food packaging products such as snack foods, coffee and candy were collected from post-consumer wastes [32].

Since the early 1990 s, the detection and recognition of waste materials to be used in concrete have escalated [36,37]. Utilization of agricultural waste such as ashes can help to make the construction industries more sustainable and eco-friendly. Furthermore, the employment of pozzolanic materials in the production of concrete for their benefits is a common practice. POFA is one of the most recent inclusions in the pozzolanic ash category. POFA is found from the incineration of palm kernel shells and palm oil husks as fuel in palm oil mills [38]. Malaysia is the second largest producer of palm oil crops in the world. According to Alsubari et al. [39], in Malaysia alone, about 4 million tons of waste ash was produced in 2010, and this manufacture rate is expected to increase, owing to the growth in the plantation of palm trees. The discarded ash is now considered as a valuable pozzolanic material, as it has satisfactory properties that can be used in the manufacture of durable concrete composites to enhance the durability performance and strength properties [40,41].

To date, very limited studies on the utilisation of metalized plastics in the production of concrete have been initiated, and they have been found that these fibrous waste materials are potential to develop the tensile strength and flexural strength of concrete. However, according to the author's best understanding, there is no research work on the combined effects of waste metalized plastic fibres and palm oil fuel ash on the performance of concrete composites. Given that the accessibility of the waste metalized plastic films and the pozzolanic nature of POFA, a comprehensive study was conducted to explore the interactive influences of WMP fibres and POFA on impact resistance, energy absorption and strength properties of sustainable concrete composites.

2. Materials and test methods

2.1. Materials

ASTM Type I OPC used in this study attained the necessities of ASTM C150 [42]. In addition, the ashes were obtained from a palm oil mill in Johor, Malaysia. To remove larger constituents and minimize the carbon particles, the ash was desiccated and sieved. POFA

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