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# Durability performance of concrete incorporating waste metalized plastic fibres and palm oil fuel ash

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## HIGHLIGHTS

- Waste metalized plastic fibres and POFA were used in the production of durable concrete.
- Incorporation of WMP fibres and POFA leads to the lower water absorption and sorptivity.
- WMP fibres can significantly affect the resistance to chloride penetration.
- WMP fibres caused a reduction in drying shrinkage.

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## ABSTRACT

With the rising quantity of waste generation from numerous processes, there has been growing attention in the consumption of waste materials in the production of construction materials to attain possible advantages. In this study, the durability performance of concrete comprising waste metalized plastic (WMP) fibres and palm oil fuel ash (POFA) was investigated. Properties studied include air content of fresh concrete in addition to sorptivity, water absorption, chloride penetration, and drying shrinkage of hardened concrete. Six concrete mixes containing 0–1.25% WMP fibres with a length of 20 mm were cast for ordinary Portland cement (OPC). Further, six concrete batches with the same fibre content were made, where 20% POFA substituted OPC. The incorporation of WMP fibres and POFA increased the air content of concrete mixtures. Furthermore, water absorption, sorptivity, and chloride penetration of concrete reinforced with WMP fibres were reduced with volume fractions of up to 0.75% for both OPC and POFA-based mixtures. The positive interaction amongst WMP fibres and POFA consequently led to the reduction in drying shrinkage of the concrete. The influence of POFA on the durability performance of concrete was noticed to be more significant at longer curing periods. The results of the study revealed that there is a promising future for the utilisation of WMP fibres in the production of sustainable and durable concrete.


## 1. Introduction

Over the last decades, the efficient management of several sorts of waste production is getting more attention to maintain sustainability in construction. The consumption of waste materials rather than natural resources is one of the fundamental concerns of waste management strategies. Reduction in environmental pollution, decreasing landfilling and discarding of wastes, and preserving raw materials are the main advantages of recycling [1–3]. In the modern lifestyle, industrialisation and mechanisation inventions generate vast quantities of solid waste materials annually. Of these, numerous sorts of non-biodegradable wastes such as plastics will remain on the earth for hundreds or thousands of years. Therefore, in the construction and building industries, the concept of sustainability persuade the utilisation of waste materials to substitute raw resources. This leads to green environment, eco-friendly and sustainable construction [4,5].

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. The overall manufacture of plastics is given an account to have raised to 288 million tons in 2012, worldwide [6–8]. Approximately half of these products are a one-use consumer, which caused critically to the generation of different sorts of plastic wastes. Therefore, mismanage of waste plastics leads to severe environmental concerns such as human's health hazards, effects on animal's life, water and 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

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plastics appropriate for this classification [9,10]. Amongst all, waste metalized plastic films which are made of a polymer and coated with a thin sheet of aluminium used by food packaging industries are unfit for reprocessing and reuse [11,12]. Currently, the main ways of disposal of such a considerable amount of waste plastics are limited to incineration and landfill. Therefore, reliable and sustainable discarding substitutions to the existing methods have become essential.

Concrete is characteristically categorised as a brittle material, due to its low energy absorption capacity and tensile strength. Conventional plain concrete is susceptible to having microcracks and spalling against liquid and gas permeability, chemical attacks, thermal deformation, and shrinkage which are practically unavoidable and mainly expected in aggressive environments. Several investigations by researchers such as Brandt [13], Nili and Afroughsabet [14], Foti [15], Mohammed [16], and Mastali and Dalvand [17] revealed that cracks permit chemicals and other substances into the concrete. In addition, the cracks accelerating the deterioration of concrete specimens, for instance, corrosion by chloride attack. Advances in modern civil engineering constructions have caused a high demand for different sorts of concrete which are essential to possess better-quality in terms of strength and durability. Therefore, to enhance the durability performance of concrete components, several ways have been proposed. Providing a solid microstructure of concrete by well-graded particle size distribution to reduce the entrance of harsh ingredients into the concrete, enhance the strength and develop the durability properties of concrete through the inclusion of mineral or chemical admixtures are some of these methods [18–20]. Nevertheless, these techniques are not adequate to improve the ductility of concrete specimens.

In regards to the said matters, fibre reinforced concrete (FRC) and high-performance fibre reinforced concrete (HPFRC) can be designed to have better strength and durability properties associated to that of conventional plain concrete [21–23]. Moreover, pozzolanic materials such as fly ash (FA), silica fume (SF), palm oil fuel ash (POFA), and ground granulated blast-furnace slag (GGBS), can be used in the production of HPFRC [24–28]. POFA is one of the most recent inclusions in the pozzolanic ash category. 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 [29–31]. The POFA has satisfactory properties that can be used in the manufacture of durable concrete composites to enhance the durability performance and strength properties [32,33].

The most significant contribution of short fibres in concrete is the capability to delay crack propagation. The internal stresses in the concrete specimens cause the creation of microcracks. The addition of discontinues short fibres can transfer the stresses within the concrete ingredients and prevent the propagation of the cracks [13,14]. Therefore, several sorts of fibres, either polymeric or metallic, are commonly used in concrete mix for their benefits. Among recycled plastics, the reinforcement of cementitious materials through recycled polyethylene terephthalate (PET) fibres has received particular attention in the technical literature [15,34].

In the last few decades, many researchers have explored the properties of concrete incorporating various kinds of plastic waste. Polyethylene terephthalate (PET) waste bottles [15,34–36] , polyethylene (PE) waste bags [37,38], polyvinyl alcohol (PVA) fibres [39,40], and waste polypropylene (PP) fibres [41,42] are the most popular waste fibres used to reinforcement of concrete. It has been found that these waste fibres are potential to be used as fibrous materials in the production of concrete to reduce the microcracks and therefore, improve the durability performance. However, the waste metalized plastic films and fibres have not been widely used as fibrous materials in the production of FRC which in fact is a large source of littering of waste plastics nowadays.

An essential deformation property of concrete is the shrinkage. According to Yin et al. [10], Yousefieh et al. [43], plastic and drying shrinkage have a severe influence on the strength and durability properties of concrete structures. Drying shrinkage is one of the most common reasons for cracks formation in concrete components. The cracks in concrete due to shrinkage may quicken other forms of detriment such as freeze/thaw damages, corrosion, and consequently, reduce the service life of concrete structures [18]. In their researches, Karahan and Atis [44] and Zhang and Li [45] for PP fibres and Passuello et al. [40] for PVA fibres ascertained that the utilisation of these fibres in concrete was capable of decreasing the drying shrinkage of concrete significantly. A similar finding has also been reported by Kim et al. [8], Kim et al. [23], and Pelisser et al. [46] on the utilisation of PET fibres. They found that the cracking caused by drying shrinkage was delayed in the concrete specimens reinforced with PET fibres as compared to those of plain concrete, which indicates the bridging action and crack controlling characteristics of these waste fibres.

Chloride attack is also one of the deterioration forms in concrete components. Chloride-induced corrosion of steel reinforced concrete structures is a durability concern, particularly in cold environments. In this regions, concrete components are frequently exposed to de-icing salt in the winter and subsequently causes crack development. The chloride ion has the superior capability to spoil the passive oxide film on steel bars, even at high alkaline environments [18,19]. This kind of problems arises because of the creation of a soluble iron-chloride complex that consequences in the deposition of loose permeable rust and discharges the chloride to continue the attack. Karahan and Atiş [44] and Zhang and Li [45] reported that the incorporation of pozzolanic material and short fibres such as polypropylene is an adequate method in controlling the entrance of harmful particles over the concrete specimens. Likewise, both Won et al. 2010 [22] and Ge et al. [47] stated that water absorption and chloride penetration were considerably reduced by the addition of PET fibres into concrete mixtures.

In addition to strength properties, the durability characteristics are significantly reflected in the evaluation of performance and possible utilisation of any novel waste material in the production of concrete. So far, there is no literature on the durability performance of concrete incorporating WMP fibres and POFA. Considering the availability of waste metalized plastic fibres and pozzolanic nature of POFA, examinations on the employment of these waste materials in the production of sustainable concrete were carried out in the Faculty of Civil Engineering, Universiti Teknologi Malaysia. Along with air content of fresh concrete, transport properties such as sorptivity, water absorption, and chloride penetration in addition to drying shrinkage were investigated.

## 2. Materials and test methods

### 2.1. Materials

ASTM Type I OPC used in this study attained the necessities of ASTM C150. Also, the ashes were obtained from a palm oil mill in Johor, Malaysia. To remove larger constituents and minimise the carbon particles, the ash was desiccated and sieved. POFA substances smaller than 150 μm were grounded by a grinder for about two hours for each four kg of raw ash. The obtained POFA followed to the necessities of BS 3892: Part 1. According to ASTM C618, it can be characterised as class C and F. However, based on the type, source, and comparatively low CaO (5.7%) content, this ash was classified as low calcium content ash. The physical properties and chemical compositions of OPC and POFA are given in Table 1.