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The impact resistance and mechanical properties of concrete reinforced with waste polypropylene carpet fibres

Hossein Mohammadhosseini [a], A.S.M. Abdul Awal [b,*], Jamaludin B. Mohd Yatim [a]

[a] Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia
[b] Jamilus Research Center, Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia

HIGHLIGHTS

- Industrial waste carpet fibre has been identified as a good fibrous material for use in concrete.
- The physical and mechanical properties of concrete containing waste carpet fibres and palm oil fuel ash are presented.
- The combined effect of carpet fibre and palm oil fuel ash in improving the impact resistance of concrete is highlighted.

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ABSTRACT

The utilization of waste materials is one of the fundamental issues of waste management strategies in many parts of the world. With the advances in cement and concrete technology, the use of waste materials in the concrete industry has developed gradually widespread because of technological, economic and ecological advantages. This paper presents the potential use of waste polypropylene carpet fibres, and highlights the impact resistance and mechanical properties of concrete with the fibres. Six volume fractions varying from 0 to 1.25% of 20-mm-long carpet fibres were used with ordinary Portland cement (OPC) concrete mixes. Another six mixes were made where OPC was replaced by 20% palm oil fuel ash (POFA) as supplementary cementing material. It has been found that the addition of polypropylene carpet fibre decreased the slump values and increased the VeBe time of fresh concrete. The inclusion of carpet fibre to either OPC or POFA concrete mixes did not improve the compressive strength at early ages. At later ages, however, the compressive strength of the mixtures containing POFA significantly increased and the obtained values were higher than that mixes with OPC alone. The positive interaction between carpet fibres and POFA leads to high tensile strength, flexural strengths and impact resistance, thereby increasing the concrete ductility with higher energy absorption and improved crack distribution. It is concluded that waste carpet fibres and palm oil fuel ash can be used as building materials in the construction of sustainable concrete.

1. Introduction

The low tensile strength and the high rigidity of concrete, subsume it as brittle materials. Higher impact resistance and energy absorption capacity are therefore needed in different applications like industrial floors, highway paving, bridge decks, etc. Additional components are necessary to enhance these properties of concrete where these requirements are essential [1–5]. Fibre reinforced concrete (FRC) is a composite material made of ordinary Portland cement (OPC), coarse and fine aggregates, and a dispersion of discontinuous short fibres. There are many types of fibres used in the concrete mixes for their benefits [6–9]. Among others, the most common fibres utilized in fibre reinforced concrete are metallic fibres, polymeric fibres for example nylon and polypropylene, glass fibres, natural fibres and fibres from pre- and post-consumer wastes. As the introduction of fibre reinforced concrete, a great deal of challenge has been led on different fibres to evaluate the real properties and advantages for each category. Over the years, various kinds of polymeric fibres have been successfully used in concrete mixtures [10–12]. Polypropylene (PP) fibres with volume fractions ranging from 0.1% to 2.0% have commonly been used as a subsidiary reinforcement in concrete and have been found potential in enhancing impact resistance and energy absorption of concrete [6,13].

* Corresponding author.
E-mail address: asmawal@yahoo.com (A.S.M. Abdul Awal).

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Generally, the ductility of concrete can be enhanced by introducing different types of fibres, such as polypropylene fibre into the concrete mixes. Fibre permits for crack bridging action, taking advantage of a mechanism that restrains crack opening and improve the energy absorption of the concrete mixtures [14–16]. Many studies have been undertaken to investigate the ductility of fibre reinforced concrete by the impact test, and it has been found that the addition of fibres considerably develops the impact resistance of the mixture [17–22].

Fibrous concrete containing pozzolanic materials has also been made and studied with conventional concrete [20,23–28]. In recent decades, detection and recognition of pozzolanic ashes as supplementary cementing materials used in concrete rapidly increased for practice in research and concrete industries. One of the newest inclusions in the ash family is palm oil fuel ash (POFA), which is obtained by burning palm oil husks and palm kernel shells as fuel in palm oil mills. This waste ash is usually available in African Sub-Sahara and South-East Asia regions where production of palm oil plays a significant role in the national economy. In 2007, approximately 3 million tons of POFA were produced in Malaysia alone, and this production rate is likely to rise due to the increased size of the palm oil tree plantation. The ash, which is disposed of without any commercial return is now considered a valuable material with good performance in improving the strength and durability of concrete mixtures [26,29–32].

Synthetic fibres were developed typically to supply the high demand for textile and carpet products. Nylon and polypropylene are the synthetic fibres most commonly employed in these industries. In waste streams, carpets are classified as textiles and are generated either from post-consumer or pre-consumer (industrial) products. Textiles account for approximately 2%–5% of all waste going to landfills in the United Kingdom. According to Carpet Recycling UK, 400,000 tons of carpet are sent to landfills annually [33]. In the USA alone, approximately 1.9 million tons of textile waste were generated in 2007, accounting for 4.7% of the total municipal solid waste; of this, 15.9% of the textile waste was recovered. Generally, in Malaysia and most of other countries industrial carpet wastes are from back and face yarns [34]. The face yarn is usually nylon or polypropylene fibres, and the back yarn is mostly in the form of woven sheets. These fibres are 50%–70% nylon and 15%–25% polypropylene. The benefits of consuming such waste fibres contain generally lower cost to process than virgin fibres, light in weight, good acid, and alkali resistance and non-absorbent of water [35,36].

In the last decades, researchers have investigated the influence of waste carpet fibres on various properties of concrete. It has been concluded that carpet fibre reduced the workability and compressive strength of concrete with reference to plain concrete without any carpet fibres. However, waste carpet fibres have been shown to exhibit a positive response in terms of flexural strength and toughness of concrete [37–39]. The combined effect of waste polypropylene carpet fibres and POFA on the properties of concrete is a new concept of study which needs extensive consideration. While a few research works have been conducted on the use of these fibres in concrete to improve general properties of concrete, it is essential to conduct an in-depth study on the behaviour of concrete with the wide range of mix proportions. Since a small quantity of short fibres has been recommended for the enhancement of the strength properties of concrete, it paves the way to use carpet fibres to obtain more detail on impact resistance of concrete containing this fibre.

Impact resistance is a significant property of fibre reinforced concrete in infrastructure construction. Numerous approaches with different guidelines have been proposed to investigate the impact resistance of concrete, for example, Charpy test, drop weight test and projectile impact test. Amongst all, the ACI committee 544 [40] recommended the drop weight method which is the most prevalent and noteworthy. In view of the accessibility and the potential advantage of waste carpet fibres and pozzolanic performance of POFA, research work on the use of POFA in concrete has been carried in the Faculty of Civil Engineering, Universiti of Teknologi Malaysia (UTM). This paper offers experimental findings on the blended influence of waste carpet fibre and POFA in enhancing the impact resistance and strength of concrete.

2. Materials and test methods

2.1. Materials

In this study, ordinary Portland cement (OPC) (ASTM Type I) was used. Raw POFA was collected from a palm oil mill in Malaysia. POFA was dried and sieved to eliminate larger materials and to reduce the carbon content. Ash particles smaller than 150 μm were ground in a Los Angeles milling device containing 10 steel bars that were 800 mm long and 12 mm in diameter for a period of two hours for each 4 kg of POFA. While moderately spherical, POFA comprises of irregular components; a typical electron micrograph of the ash being displayed in Fig.1. The chemical analysis of OPC and POFA was conducted using energy dispersive spectrometry, and the results along with the physical properties are given in Table 1. The data shows that POFA is reasonably rich in silica content (62.60%) as associated to that of OPC (20.40%). The amount of CaO, however, is slightly less i.e. 5.7%. The amount of iron content (5.02%) is comparable to that of OPC, and according to ASTM C618-15 the ash may be categorized as in amongst class C and class F though, considering the source and type, the ash is neither of class C nor of class F.

The variation in carbon content of any ash is contingent on the ignition procedure. Loss on ignition (LOI), for instance, noticed in this study is 6.25% which is slightly greater than the maximum standard value of 6.0% specified in ASTM C618-15 for both class F and C. Nevertheless, by a maximum limit of 10% carbon content for class N, the usage of class F pozzolan comprising up to 12% LOI may be permitted if either satisfactory performance record or experimental results are available. It is significant to mention that the 28 days strength activity index of POFA with OPC has been found to be considerably higher (112) than that of the minimum value (75) recommended in the similar standard. While strength activity index is not a direct measure to be deliberated as a value of compressive strength, but is a sign of reactivity with a given cement to estimate the involvement of the mineral admixture to the strength improvement of concrete [31,32].

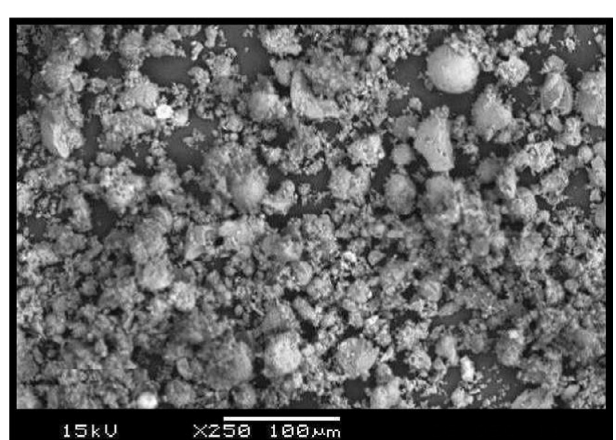

Fig. 1. Scanning electron micrograph of POFA.