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# Microstructure and residual properties of green concrete composites incorporating waste carpet fibers and palm oil fuel ash at elevated temperatures

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A B S T R A C T

With the increasing amount of waste generation from different processes, there has been a growing interest in the use of waste in producing sustainable building materials to achieve potential benefits. This study investigated the influence of waste polypropylene carpet fibers and palm oil fuel ash (POFA) on the microstructure and residual properties of concrete composites exposed to elevated temperatures. Four mixes containing carpet fibers (0% and 0.5%) and POFA (0% and 20%) were prepared. The specimens were exposed to high temperatures (200, 400, 600 and 800 °C) for 1 h. The fire resistance of the concrete specimens was then measured in terms of mass loss as well as both residual ultrasonic pulse velocity (UPV) and compressive strength. The role of carpet fibers and POFA was investigated through the analysis of the microstructure in terms of scanning electron microscopy (SEM), thermogravimetric analysis (TGA) and differential thermal analysis (DTA). The results revealed that the addition of waste polypropylene carpet fibers to the concrete matrix significantly enhanced the fire resistance and residual compressive strength in addition to eliminating the explosive spalling behavior of the concrete composites at elevated temperatures. The fire resistance of the concrete mixtures was further enhanced by the inclusion of POFA. The study revealed that the utilization of waste carpet fiber and palm oil fuel ash in the production of sustainable green concrete is feasible both technically and environmentally.



## 1. Introduction

There is no doubt that cleaner and more efficient management of various forms of waste generation is receiving more attention in order to maintain sustainability in green construction. The utilization of waste materials is one of the fundamental issues of waste management strategies in many parts of the world. According to Guo et al. (2014) and Salesa et al. (2017), the advantages of recycling include reducing environmental pollution, reducing landfilling and disposal of wastes and preserving natural resources. Fire represents one of the most severe potential risks to which structures may be subjected. The behavior of structures exposed to elevated temperatures is mostly associated to stress distribution, cracking, spalling and surface micro cracking. In some circumstances, the concrete structure is exposed to elevated temperatures and pressures throughout its service for a substantial period, for example, concrete in a reactor vessel, coal gasification, nuclear plant and other applications. Noumowe et al. (1994) and Kalifa et al. (2001), reported that the significant impacts of high temperature on concrete structure are the dehydration of cement paste, variation in water content, increase in porosity, thermal expansion and cracking, modification of pore pressure and decrease in strength and thermal spalling owing to extreme pore pressure.

A great deal of attempt has been made and various practices have been used to manage high temperatures as well as evaluate the residual performance of concrete structures. Guo et al. (2014) stated that to develop concrete properties, fibrous materials can be added into the concrete mixture. The purpose of such addition is to enhance its toughness, tensile and flexural strengths, resistance against impact loads and other mechanical properties, reported by Rashad (2015a,b). In their studies, Silva et al. (2014) and Mugume and Horiguchi (2014) ascertained that fibrous materials have exhibited good performance in developing the fire resistance capacity of concrete components. Recently, the detection and recognition of fibers for the reinforcement and improvement of concrete have rapidly increased the need for practice in research,

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development and concrete industries. According to Sanchayan and Foster (2016), various kinds of fibers, either polymeric or metallic, are generally utilized in concrete mixture for their benefits. Shuaib and Mativenga (2016) also stated that, the most common fibers used in concrete are steel, glass and synthetic fibers such as nylon and polypropylene (PP) as well as natural fibers and fibers from pre- and post-consumer wastes. Technical developments brought forward the advancement of fibers with different materials, geometric forms and properties to increase the advantages in concrete constructions. Modern manufacturing methods and demands on fibers, which are to be used in concrete have since been developed. Therefore, different features of fiber-reinforced concrete have been introduced to the market globally (Yu et al., 2016).

In general, synthetic fibers are industrialized to supply the high demand for textile and carpet products. Nylon and polypropylene are some of the most commonly employed types of synthetic fibers in the said industries. In waste streams, carpets are classified as textiles and are generated from either pre- or post-consumer products. According to Carpet Recycling UK, cited in Sotayo et al. (2015), 400,000 tons of carpet are sent to landfills annually. 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. Industrial carpet wastes are from back and face yarns. As Mohammadhosseini and Awal (2013) point out, the back yarn is mainly in the form of woven sheets while the face yarn is usually polypropylene or nylon fibers. These fibers are 50–70% nylon and 15–25% polypropylene. Waste carpet fibers can be potentially used in the manufacturing of concrete as doing so is a hypothetically effective method to reduce the disposal of waste materials and at the same time decrease the amount of raw materials used in concrete industries. Awal and Mohammadhosseini (2016) ascertained that, the concrete manufactured containing waste carpet fibers would be lightweight and possess good acid and alkali resistance.

With the growing demand for supplementary cementing materials, smart and efficacious conservation of construction materials comprising several by-product waste have received more attention for the sustainability of green construction (Sua-iam and Makul, 2014). Alsubari et al. (2016) point out, the utilization of pozzolanic ashes as supplementary cementing materials in concrete is an effective way to develop the properties of concrete composites. In recent periods, a great deal of attention is being focused on the potential use of pozzolanic ashes in concrete. These pozzolanic materials are used in all corners of the world for their technical, economic and ecological benefits. According to Mohammadhosseini et al. (2015,2016), one of the latest inclusions in the ash group is palm oil fuel ash (POFA), which is obtained by burning palm oil husks and palm kernel shells as fuel in palm oil mills. Khankhaje et al. (2016) and Mujah (2016) reported that in 2007, approximately three million tons of POFA were produced in Malaysia, and this production rate is expected to rise due to the increased size of the oil palm tree plantation in the country. Lim et al. (2015) stated that the ash, which is disposed of without any profitable return, is now considered as a valuable material with good performance in improving the strength and durability of concrete mixtures.

Concrete has been presented to have a number of benefits when used in constructions. However, it suffers from a main weakness, which is its high brittleness. Due to the importance of concrete performance at elevated temperatures and in fire, several studies by Arioz (2007), Behnood and Ghandehari (2009), and Ateş and Barnes (2012) have been previously carried out in regards to the subject of fiber-reinforced concrete at high temperatures. The addition of pozzolanic materials in concrete was also reported by Rashad (2015a,b) for fly ash, Xiao and Falkner (2006) for silica fume, and Awal et al. (2015) for POFA with satisfactory performance at elevated temperatures. Amongst fibers, the inclusion of polypropylene (PP) fibers in concrete mixtures was found to perform very efficiently. Kalifa et al. (2001) and Poon et al. (2003) stated that steel and polypropylene fibers could be used to decrease cracking and spalling in addition to enhancing the residual strength of concrete at elevated temperatures. According to the findings, it was ascertained that most properties of concrete reduced with an increase in temperature, especially for polypropylene fiber-reinforced concrete mixtures.

As the addition of polypropylene fibers and pozzolanic materials has been recommended by Noumowe (2005) and Bonakdar et al. (2013) for the possible decreasing of spalling of concrete at high temperatures, it paves the way for the application of waste carpet fibers and POFA to develop enhanced performance of concrete at elevated temperatures. However, research on the utilization of such waste in concrete has not yet been conducted. Taking into account the availability of the waste materials and pozzolanic activities of the ash, POFA in particular, extensive research work has been carried out in the Department of Structure and Materials of Universiti Teknologi Malaysia (UTM) to explore the potential benefits of producing sustainable building materials.

Given the aforementioned argument, the purpose of this study was to investigate the combined effects of waste carpet fibers and POFA on the performance of concrete at elevated temperatures in addition to understanding the way carpet fibers contribute to the reduction in spalling in comparison to plain concrete without any fibers. Although this research includes an investigation of industrial waste carpet fibers available, the conducted experiments and analyses are based on one single type of fiber, namely polypropylene carpet fiber. The work has been focused on performance of concrete containing carpet fibers exposed to elevated temperatures, but rather it is believed that technical issues have to be understood and fixed right before utilization of any type of waste fibers in concrete. In this study, a comparison was made amongst the compressive strength and ultrasonic pulse velocity (UPV) of both concrete mixtures containing carpet fibers and plain concrete when exposed to high temperatures. Thermogravimetric analysis (TGA), differential thermal analysis (DTA) and scanning electron microscopy (SEM) were carried out.

## 2. Materials and experimental study

### 2.1. Materials

Type I ordinary Portland cement (OPC), which achieved the requirements of ASTM C 150-07, was used in this research. The palm oil fuel ash (POFA) was collected from a palm oil mill in Malaysia. The raw POFA was subsequently finely ground in a Los Angeles milling device containing ten steel bars that were 800 mm long and 12 mm in diameter for a period of 2 h for each 4 kg of POFA. The ash conformed to the requirements of BS3892: Part 1-1992 and according to ASTM C618-15, may be categorized as in between class C and F. However, considering the source and sort, the ash was neither of class C nor F. The specific gravity and Blaine fineness of the used POFA were 2.42 and 4930 ($cm^2/g$). The chemical analysis of both OPC and POFA was conducted using energy dispersive spectrometry. The obtained results along with the physical properties are given in Table 1.

Mining sand with saturated surface dry condition passing through a 4.75 mm sieve, with fineness modulus of 2.3, specific gravity of 2.6 and 0.7% water absorption, was used as the fine aggregate. On the contrary, crushed granite with a maximum size of 10 mm, specific gravity of 2.7 and 0.5% water absorption was used as the coarse aggregate. Throughout the study, supplied tap water