



Properties of nano silica modified rubbercrete



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ARTICLE INFO

Article history:

Received 28 September 2015

Received in revised form

25 January 2016

Accepted 1 February 2016

Available online 6 February 2016

Keywords:

Rubbercrete

Nano silica

ITZ

MIP

Impact resistance

Compressive strength

ABSTRACT

Inclusion of crumb rubber from scrap tires in concrete as partial replacement to fine aggregate in production of rubbercrete has provided many beneficial impacts to both environments and concrete. Many properties of rubbercrete are improved compared with conventional concrete. However, drawbacks such as reduction in rubbercrete strengths have limited the application of rubbercrete drastically. Therefore, this paper presents a new method on producing rubbercrete with comparable compressive strength to the reference mixture (0% of crumb rubber) by adding nano silica. Twenty four mixtures, with four levels (0%, 10%, 25% and 50%) of crumb rubber replacement to fine aggregate by volume and six levels of nano silica addition (0%, 1%, 2%, 3%, 4% and 5%), were prepared and tested. The microstructure of these mixtures is also investigated and analyzed. It has been found that the inclusion of nano silica would refine the size of the pores and densify the interfacial transition zone between cement matrix and aggregate in hardened rubbercrete. This has resulted rubbercrete with fair compressive strength compared to conventional concrete.

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1. Introduction

Massive volume of scrap tires are being discarded annually with average of 250, 10 and 3.4 million tons in United State, Turkey and European Union, respectively (Demir et al., 2015; Onuaguluchi and Panesar, 2014). Globally, more than 500 million units of waste tires were being discarded without any treatment each year after the end of their service life (Thomas et al., 2016). This increasing numbers has raised concern worldwide due to the threat it poses directly and indirectly to the human health, safety and the preservation of the environment. The deposition of scrap tires in landfills and dumpsites serve as a breeding ground to pests and vermin. In addition, these scrap tires are scarcely biodegradable in nature over time and poses a haze danger in case of fire (Pelisser et al., 2011). Hence, recycling of scrap tires as crumb rubbers (CR) in concrete has become one of alternatives in sustaining the ecological balance with also an added value of economic significant (Guo et al., 2014).

CR from outer part of scrap tires is used as partial replacement to fine aggregates in Portland cement concrete and the concrete produces from this replacement is known as rubberized concrete, crumb rubber concrete or rubbercrete. Rubbercrete exhibits

numerous benefits compared to conventional concrete such as lower density (Demir et al., 2015), increased ductility (Shu and Huang, 2014), enhanced plastic capacity (Mohammed et al., 2011), higher toughness (Mohammed, 2010), higher impact resistance (Ganjian et al., 2009), better resistance to chloride penetration (Bravo and Brito, 2012), lower thermal conductivity (Mohammed et al., 2012), higher noise reduction factor (Li et al., 2004b) and better electrical resistivity (Onuaguluchi and Panesar, 2014). It has also been known to have better energy dissipation, durability and damping ratio (Youssf et al., 2014).

However, the main drawbacks of rubbercrete are decreasing in strengths (compressive, flexural, tensile and splitting) and Young's modulus as the partial replacement of CR to fine aggregate increased. The lower strength of rubbercrete is due to the weak bonding between cement matrix and the CR particles. This is attributed to the hydrophobic properties of CR due to the zinc stearate application during tires manufacturing (Youssf et al., 2014). The non-polar layer of CR repels water and traps air around it leading to increasing thickness of the interfacial transition zone (ITZ) between the CR and cement matrix, resulting in weak bond (Onuaguluchi and Panesar, 2014; Mohammed et al., 2012). Stress concentration on this weak bond causes formation of micro cracks hence leading to premature failure (Thomas et al., 2016; Mohammed et al., 2012; Li et al., 2016; Sadek and El-Attar, 2015).

Thus, to widen the practical application of rubbercrete and increasing its acceptability in the construction industry, it is essential

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to enhance its strengths. Therefore, to produce rubbercrete with higher strengths, researchers have tried to improve the bond between CR and cement matrix through several surface treatment methods to CR particles. [Rostami et al. \(1993\)](#) treated the surface of the CR and results showed that surface treatment using water, carbon tetrachloride solvent, and latex admixture cleaner increased the compressive strength by 16%, 42% and 57%; respectively compared to control mix. [Li et al. \(1998\)](#) pre-coated the CR with cement paste and METHOCEL cellulose ether solution. They reported that the strength of rubbercrete was slightly improved using cement paste's pre-coating whilst the ether solution reduced the strength of rubbercrete. [Segre and Joeke \(2000\)](#) reported that CR surface treatment using aqueous NaOH has enhanced the bond between cement matrix and CR hence resulted higher strengths. [Albano et al. \(2005\)](#) have partially replaced the fine aggregate in concrete with CR pre-treated with NaOH and silane A-174 coupling agent by weight proportion to observe the effect of the treatment on the mechanical properties of rubbercrete. They found that neither treatments using NaOH nor silane coupling agent succeed to increase the mechanical strength of the rubbercrete. [Gesoglu and Guneyisi \(2007\)](#) have studied the effect of inclusion 10% silica fume as partial replacement of cement on the performance of rubbercrete. Their findings indicated that silica fume enhanced the strength and chloride penetration resistance of the rubbercrete through formation of stronger bond between CR and cement matrix. Yet, the strength of the rubbercrete was recorded to be lower than the control mix. [Balaha et al. \(2007\)](#) investigated the effect of using 10% concentrated NaOH, polyvinyl acetate (PVA) and 15% silica fume in the rubbercrete mixtures. The NaOH, PVA and silica fume were observed to increase the strength of rubbercrete compared to the non-treated mixtures with slightly similar percentages of reduction: 14%, 15% and 17%, respectively. [Chou et al. \(2010a\)](#) treated the CR with organic sulfur to promote the production of hydrophilic group on the surface of the CR. They observed that treated CR increased the strength of rubbercrete. Next, [Chou et al. \(2010b\)](#) studied the effect of partial oxidation of CR on the strengths of rubbercrete. With manipulation of temperature, the oxidation process promotes the production of hydrophilic group on the surface of CR which led to stronger bond with cement matrix and resulted in higher strength of rubbercrete. However, this method is economically unviable for construction application as the end product would be costly. [Pelisser et al. \(2011\)](#) used NaOH and 15% silica fume by mass fraction to enhance the strength of the rubbercrete. They reported that CR treated with NaOH and rubbercrete incorporated with silica fume has lower percentage of strength reduction compared to rubbercrete without silica fume. [Corinaldesi et al. \(2011\)](#) have investigated the performance of rubbercrete containing limestone powder as filler and an acrylic-based superplasticizer admixture. They observed that both materials reduced the porosity of the rubbercrete thus increased its strength comparable to the reference mixture. [Turki et al. \(2012\)](#) also reported an enhancement in strength of the rubbercrete with 5% replacement of cement with silica fume and limestone powder in rubbercrete mixture. Nevertheless, the strength was observed to be lower than of the conventional concrete. [Azevedo et al. \(2012\)](#) utilized fly ash and metakaolin as a cement replacement in rubbercrete to improve its strengths. Although fly ash and metakaolin has different hydration rate, the result shows a synergy between fly ash and metakaolin in enhancing the strengths of rubbercrete. [Huang et al. \(2013\)](#) and [Dong et al. \(2013\)](#) employed two stage surface treatments on the CR by using silane coupling agent and cementitious coating. Treatment with silane coupling agent was efficient in gaining the strength of rubbercrete while execution of both stages of surface treatment were observed to be more effective compared to single stage application. [Meddah et al. \(2014\)](#) treated the surface of the CR with NaOH and glued fine aggregate to the CR to increase roughness of the CR's surface. However, they concluded that the treatment

method is ineffective in improving the strength of the rubbercrete. [Onuaguluchi and Panesar \(2014\)](#) investigated the effect of pre-coating of the CR with limestone powder and addition of silica fume to the cement of the rubbercrete mixtures. Rubbercrete with coated CR and silica fume addition exhibited an increase in strength up to 29% compared to the control mix. This increment was linked to the positive interaction between the limestone powder and silica fume which enhanced the bond between CR and cement matrix. [Thomas and Gupta \(2015\)](#) studied the effect of partially replacing fine aggregate within rubbercrete with three different sizes of CR. They reported that the strengths and the resistance of rubbercrete to sulfate attack were lower than the control mix. On recent note, [Li et al. \(2016\)](#) treated the waste tire fiber in rubbercrete with silane coupling agent and carboxylated styrene-butadiene rubber latex. The treatment was observed to enhance the bond between CR and cement matrix, thus increase the compressive and flexural strength of the rubbercrete compared to the reference mix by 4% and 13% respectively.

However, [Dong et al. \(2013\)](#) and [Shu and Huang \(2014\)](#) have indicated that, methods of CR treatments exhibited insignificant effect on enhancing strengths of rubbercrete comparable to conventional concrete. Therefore, the application of rubbercrete in the construction industry is too limited due to its uncompetitive strength compared to other types of concrete.

On the other hand, emerging developments in nano technology exhibits a convincing future in the advancement of material at nano scale. Nano technology has allowed the manipulation of matters at the atomic level, thus enabling researchers to control the properties of the outcome product. Nano-engineered materials are proven to have higher performance compared to their large-scale counterpart due to their nano sizes. In construction industry, the novelty of nano silica through this technology has provided solution for the demands of high performance material with competent product end-cost ([Mukharjee and Barai, 2014b](#)). Studies have shown that nano silica has the ability to improve the strength of concrete. Its large area-to-volume ratio gives advantage to nano silica to act as physical filler in filling nano voids between larger particles within cement aggregates ([Abd.El.Aleem et al., 2014](#)). It also acts as an activator to Pozzolanic reaction, which further produces more C–S–H gel leading to enhancing the microstructure of concrete ([Nili and Ehsani, 2015](#); [Mukharjee and Barai, 2014a](#)). In addition, nano silica leads to reduction of capillary porosity and reduces permeability of concrete due to the blockage effect of nano silica ([Du et al., 2014](#)). Nano silica also helps in densifying the ITZ between aggregates and cement matrix which leads to better bond and consequently enhancing the strengths of the concrete ([Mukharjee and Barai, 2014c](#)). Therefore, the main objective of the research work reported in this paper is to investigate the properties of rubbercrete containing nano silica.

2. Materials and experimental program

2.1. Materials

Materials used in preparations of dry rubbercrete mixtures were ordinary Portland cement, fly ash (F), river sand (fine aggregate: FA), nano silica (NS), mineral coarse aggregates (CA) with the maximum nominal size of 10 mm, crumb rubber (CR) and potable water. The chemical compositions of the cementitious/pozzolanic materials are shown in [Table 1](#). The ordinary Portland cement (OPC) is type 1 conforming to the requirements of ASTM. The fly ash was classified as class F with total amount of silicon oxide (SiO₂), aluminum oxide (Al₂O₃) and iron oxide (Fe₂O₃) of 88.48% and loss of ignition less than 6% according to the specification of ASTM C618 ([American Society for Testing and Materials, 2005](#)).

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