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Thermal properties of cement mortars containing waste glass aggregate and nanosilica

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Abstract

In recent years utilization of solid waste in building materials has gathered spectacular attention. One material with potential applications, especially in cement-based composites, is waste glass. The aim of this study was to evaluate the possibility of manufacturing sustainable cement mortars with the use of nanosilica (NS) and brown soda-lime waste glass (WG) fine aggregate. The mechanical and thermal properties of cement mortars containing WG aggregate and nanosilica, were analyzed in terms of waste glass and nanosilica content. Ordinary fine aggregate (river sand) was replaced with WG fine aggregate at a ratio of 100% by weight. Moreover, 0, 1 and 3 wt% of NS was incorporated to cement mortar. The experiment revealed that the presence of WG fine aggregate significantly decreased the thermal conductivity of the cement mortars and that furthermore, the sorptivity coefficient decreased. The study has shown that WG fine aggregate can be a successful substitute for natural fine sand without leading to mechanical deterioration and by significantly improving thermal properties of cement mortars. Additionally, the incorporation of nanosilica (especially in higher contents – 3 wt%) leads to a further decrement in thermal conductivity and sorptivity and improves compressive strength.

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Keywords: cement mortar; compressive strength; nanosilica; thermal conductivity; waste glass

1. Introduction

The recycling of municipal solid waste is a major problem for municipalities worldwide. In the last few decades, the utilization of waste materials as recycled additives in building materials has gathered spectacular attention.

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Currently glass is one of the least recycled materials in the majority of countries and requires the consumption of relatively large amounts of energy for the processing of the raw constituents. Theoretically, glass can be recycled many times without a change in its chemical properties, although due to high levels of impurity, colored waste glass has a low recycling rate. Therefore, various attempts have been made in order to utilize waste glass (WG) in building materials, especially cement-based composites. Due to its similarity to natural sand, waste glass (i.e. all commercial glass products containing more than 70% SiO_2) [1] can be successfully incorporated to cementitious composites as a powder or aggregate (fine and coarse) [2].

The use of recycled materials as an aggregate in concrete has recently become popular in terms of reducing the consumption of natural aggregate [3]. However, in the case of WG applications, there is a threat of alkali-silica reaction (ASR) occurring Amorphous silica can be dissolved in glass under alkaline conditions to form an ASR gel, which provides a possibility for its expansion and cracking. ASR is a surface-area dependent phenomenon and the fineness of glass aggregates has a significant impact on the potential deterioration of cement-based properties. Moreover, ASR depends on the color of the glass used (different chemical composition of glass). As such, considerable research has focused on the partial replacement of natural sand with fine and coarse waste glass, in order to suppress ASR [2,3]. Studies have shown that partial replacement (up to 40%) [2,3,4] of fine aggregate with WG, is most beneficial in improving the mechanical properties of cement mortars. Moreover, it has been observed that the incorporation of coarse WG aggregate causes a deterioration in the mechanical properties of cement-based composites, due to the cracking of the WG coarse aggregate [5]. Therefore, the utilization of fine WG aggregates along with natural coarse aggregates, is much more beneficial in the incorporation of cementitious-composites. However, from the perspective of sustainability, substitution of 100% of natural fine aggregate with WG fine aggregate, would be much more desirable.

Studies undertaken by Xi et al. [6], have shown that incorporation of 100% of green and brown WG fine aggregate in mortars, has proven to be innocuous, regardless of the replacement level, whereas clear glass can exhibit potentially deleterious properties. Recently it has been reported that cement-based composites containing up to 100% replacement ratio of brown-colored soda-lime fine aggregate, with an aggregate size less than 2.36 mm [7] and 4.75 mm [8], can successfully be incorporated into concrete, without large ASR expansion.

One of the methods of suppressing the ASR effect in cementitious composites, is to incorporate various admixtures and additives such as fly ash, ground blast furnace slag, metakaolin, silica fume, or nanosilica [3,4]. In addition, reports show that even fine waste glass powder greatly reduces the ASR expansion induced by glass aggregate [2]. Studies conducted by Aly et al. [9], have shown that glass powder hinders expansion in comparison to control specimens. Moreover, hybrid incorporation of waste glass and nanosilica greatly reduces the possibility of ASR [9]. Besides the potential of admixtures and additives for reducing ASR expansion, they also positively affect various properties of cement-base composites, including the mechanical and thermal ones.

In recent years, thermal insulation of buildings has gathered spectacular attention. It has been established that the largest energy savings can be made through the proper insulation of a structure. Studies undertaken by Alani et al. [10], have shown that replacement of fine aggregate with WG aggregate significantly decreases the thermal conductivity of screeds. Equivalent results have been reported by Krishnamoorthy et al. [11], where the partial replacement of fine aggregate with WG fine aggregate (from 10 to 50%) in concrete, gradually decreased thermal conductivity with an increase in the recycled glass content of a specimen. Also, Guo et al. [12] has reported that a particularly high ratio of natural aggregate with a WG replacement, can decrease the thermal conductivity of architectural mortars. Besides their practical properties, architectural cement mortars also have the potential for application as façade materials, due to their aesthetic qualities.

As such, the utilization of waste glass along with the proper admixtures might be a good way to create sustainable cement mortars, with improved thermal and mechanical properties. With this purpose in mind, various silica materials, namely aerogels, silica fume, silica gel and recently nanosilica, can be incorporated. Studies have shown that silica fume and silica gels can be beneficial in reducing the thermal conductivity of cement pastes and mortars, by decreasing the density of samples [13]. Aerogels contribute significantly to a decrement in the thermal conductivity of cementitious-composites, although they dramatically affect the mechanical properties of cementitious composites [14]. Recent studies have promoted the utilization of nanosilica as an additive to improve both the mechanical and thermal properties of cementitious composites. Studies undertaken by Jittabut et al. [15], devoted to the determination of the thermal conductivity of cement pastes modified with nanosilica particles, have