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Review

Recycled waste glass as fine aggregate replacement in cementitious materials based on Portland cement

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HIGHLIGHTS

- Glass sand increased mixture workability, bleeding and segregation, whilst it decreased density.
- Glass sand decreased mechanical strength and drying shrinkage, whilst it increased ASR.
- As the particle size and glass content increased as the ASR expansion increased.
- Green sand colour effected ASR expansion. MK, FA, slag, SF, Ni_2CO_3, $LiNO_3$ can it.
- Glass increased chemical and fire resistance. At long terms, it increased carbonation resistance.

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ABSTRACT

Disposal of waste glass derived from container or packaging glass, flat glass, domestic or tableware glass and continuous filament glass fibres is one of the major environmental challenges. This challenge continues to increase with increasing the amount of waste glass and decreasing the capacity of landfill space. Therefore, studies have been carried out to find practical ways to recycle waste glass in building materials such as cement, mortars, concretes and blocks. This paper presents an overview of the previous studies carried out on the use of waste glass as partial or full natural fine aggregate replacement in traditional mortar/concrete mixtures based on Portland cement (PC). Fresh properties, mechanical properties, abrasion resistance, water absorption, chloride ion penetration, permeability, chemical resistance, carbonation resistance, drying shrinkage and alkali-silica reaction (ASR) expansion of mortar/concrete mixtures containing waste glass as fine aggregate replacement have been reviewed.

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1. Introduction

Glass is produced in many forms, including packing or container glass, flat glass and bulb glass [1]. The uses of glass products have increased tremendously resulting in large amounts of waste glass. In 2005, the estimated production of the global glass was 130 Mt. Container glass accounts was approximately fifths and flat glass was approximately one third of the production. Production volumes for fibre and special glass are small. The European Union produced approximately 33 Mt of glass, whilst China and USA produced approximately 32 and 20 Mt, respectively [2]. In 2004, the United Nations estimated the volume of yearly disposed solid waste to be 200 million tonnes, 7% of which is made up of glass the world over. In 2010, the percentage of waste glass was approximately 4.6% of total MSW generation in the United States (Fig. 1) [3]. In 1999/2000, the percentage of waste glass was approximately 2.1% of total MSW generation in India [4]. In Turkey, this amounts to 120,000 tonnes, 80,000 tonnes of which are recycled, with Germany reporting 3 million tonnes of waste glass being recycled [5]. In 2006, Americans generated approximately 12 million tonnes of glass, of which only 22% was recovered for recycling [6]. Of this small percentage of recycled glass, most (90%) is used to make new containers, whereas the remaining 10% is used for secondary applications, such as roadbed aggregates and fibreglass insulation [6]. In Hong Kong it was estimated that approximately 373 tonnes of waste glass is generated daily in 2010. Approximately 4500 tonnes of the glass were recycled annually, the recycled percentage was 3.3% and the remaining 96.7% was sent to landfill for direct dumping [7]. In 2002, the annual waste of glass materials in Taiwan was approximately 600,000 tonnes [8], whilst the amount waste of glass dumped into landfills was approximately 0.52 million tonnes in 2009 [9]. In 2010, approximately 425,000 tonnes of waste glass were produced in Portugal and only 192,000 tonnes of them were recycled [10]. In 2006, the waste glass consumption was 2.3% and 2% in eastern Africa and Middle Africa, respectively [11]. In 2005, the recycling rate of waste glass was approximately 67% and 91% in Republic of Korea and Japan, respectively [12]. Overall, there is unclear information about the whole quantity of waste glass in the world, because of the lack of information from different countries like the Middle East as an example. However, it was estimated that the total amount of waste glass generated in the EU-27 in 2007 was 25.8 Mt. This result from a total production of glass in the EU-27 of 37.4 Mt in 2007. The extra-EU trade of manufactured glass represented only 5–10% of the production (Fig. 2) [13,14]. The amount of waste glass is gradually increased over the recent years due to an ever-growing used of glass products. Most of waste glass that is produced is dumped into landfill sites or roadways sites (Fig. 3). With increasing scarcity of landfill sites and the fact that glass is not biodegradable, landfills did not provide an environmental friendly solution.

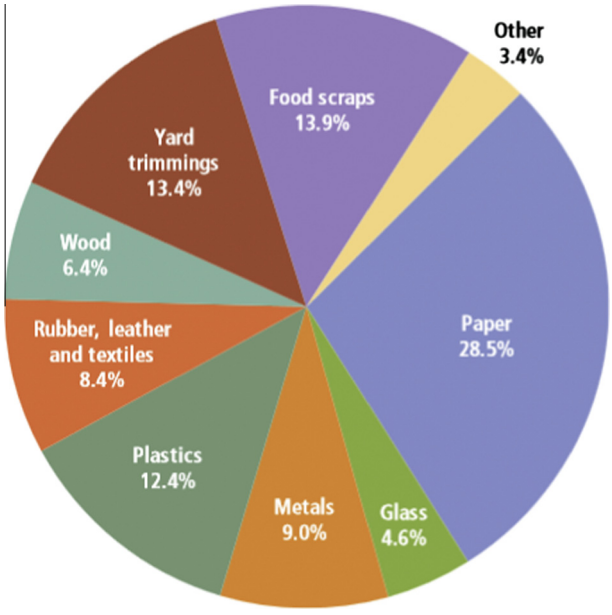

Fig. 1. Percentage of waste glass related to total MSW generation in the United States [3].

Waste reduction and recycling are very important elements in a waste management framework because they help to conserve natural resources, reduce demand for valuable landfill space [7], diminish the need of raw materials to make new product, reduce air and water pollution, reduce energy and create new jobs. It worth mentioning that in European zero waste program it is estimated that resource efficiency improvements all along the chains could reduce material inputs needs by 17–24% by 2030 and a better use of resources could represent an overall saving potential of €630 billion/year for European industry. Furthermore, more than 180,000 direct jobs in the EU by 2020, in addition to the estimated 400,000 jobs that will be created by the implementation of the waste legislation in force. They will lead to satisfying between 10% and 40% of the raw material demand in the EU, while contributing to achieving the EU target to reduce greenhouse gas emissions by 40% – 62 Mt of CO_2/year would be avoided in 2030 [15]. Anyway, the use of recycled glass in the manufacturing of new glass reduces energy consumption, raw materials use, and wear and tear on machinery. However, not all used glass can be recycled into new glass because of impurities, cost, or mixed colours [16]. Indeed, there is a need to establish new options for recycling waste glass. One important option is to employ waste glass in building materials. Since 1963, the first study had been carried out on the use of glass chips to produce architectural exposed aggregate for concrete [7]. Later, owing to the excellent hardness of glass, extensive researches have been carried out to utilize recycled glass as coarse or fine aggregate in concrete and mortar [5,17–20]. Crushed glass particles that were used as aggregate are generally angular in shape and may contain some elongated and flat particles. The degree of angularity and the quantity of flat and elongated particles depends on the degree of crushing. Smaller particles, resulted from extra crushing, exhibited somewhat less angularity and reduced quantities of flat and elongated particles [1]. Other investigations studied the feasibility of milling the glass cullet into

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