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Efficiency of waste marble powder in controlling alkali–silica reaction of concrete: A sustainable approach

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HIGHLIGHTS

- Influence of WMP in controlling the ASR expansion was examined.
- Micro-structural behavior due to ASR was explored using SEM and EDS analysis.
- WMP can be effectively used to control ASR expansion leading to sustainable and environment friendly construction.

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ABSTRACT

Recycling of wastes in building materials is gaining a lot of attention worldwide. This not only conserves natural resources but also enhances the properties of existing building materials leading to economical and environment friendly construction. The main aim of this study was to explore the efficiency of waste marble powder (WMP) in controlling alkali silica reactivity (ASR) of concrete. For this purpose, WMP was obtained from a marble industry. To initiate the ASR phenomena, reactive aggregate was used in the study. Mortar bar specimens prepared with WMP as cement replacement material at 10%, 20%, 30% and 40% replacement levels (by cement weight) were evaluated in the standard ASTM C1260 test method. Compressive strength and thermal analysis tests were performed to investigate the effect of WMP on strength development of concrete. Results of compressive strength and thermal analysis showed improved strength after 10% of cement replacement with WMP. Moreover, 28% and 50% reduction in mortar bar expansion was observed after replacing 10% and 40% of cement with WMP, respectively. Scanning electron microscopic images also showed no signs of ASR cracking for mortar bars incorporating WMP. However, presence of cracks due to ASR was observed in control specimens. Furthermore, energy disperse X-ray spectroscopy (EDS) showed that amount of alkalies reduced after replacing cement with WMP, leading to overcome ASR expansion. Therefore, based on the results WMP can be effectively used to control ASR expansion leading to durable, sustainable and economical construction.

1. Introduction

Problem of alkali silica reaction (ASR) in concrete is common around the world. Alkalies (mainly due to cement) release hydroxyl ions in concrete. Hydroxyl ions have the tendency to react with silica of reactive siliceous aggregates. Amount of hydroxyl ions increases as a result of higher alkalies leading to rapid reaction [1]. This reaction results into the formation of ASR gel, which absorbs moisture/water and expands. ASR gel can cause minor cracking leading to major structural distress. It is a time taking process and results into damage of concrete structures.

ASR is considered deadly for concrete and referred as "cancer of concrete" [2]. Different factors like, reactive aggregates, alkali content and available moisture play an important role in ASR propagation in concrete. Mechanical properties as well as durability properties are greatly affected as a result of ASR in concrete [3,4]. Different case studies are available regarding ASR in structures [5]. Problem of ASR was reported in different structures such as hydroelectric plant in Atlantic Canada, Elgeseter Bridge Norway, Warsak and Tarbela dam in Pakistan [6–8]. Tensile strength along with elastic modulus are the properties of concrete, considered greatly affected by ASR [3,9].

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A lot of researches deal with the ways to control ASR [1]. Use of waste materials is considered as the most suitable way to control ASR [10]. Alkalies concentration in concrete can be reduced by using waste materials like silica fume, low calcium fly ash, slag and other waste materials leading to overcome ASR problem [10]. Effectiveness of waste materials against ASR is mainly due to reduced porosity, alkalies reduction and decreased aggregates silica dissolution [11].

Marble has been used in construction works for a long time [12]. It is mainly used in tiles and indoor flooring [13]. Marble deposits are present in many parts of the world including Italy, Brazil, Spain, Sweden, Belgium, France and Egypt [14,15]. In Turkey only, 40% of world's marble deposits are present [16]. A lot of marble is wasted every year as a result of quarrying operations and processing works. Wastage of marble only during processing and polishing work is approximately 70% of the total marble waste generated [13]. This waste is dumped in vacant spaces or discharged into the water bodies leading to serious environmental issues [17]. Now a days, researchers are trying to utilize waste materials in construction to control environment related issues [18–21]. Utilization of waste marble powder (WMP) in construction activities is gaining a lot of attention. WMP can be used as a potential stabilizing agent to improve the properties of weak clayey soils [12]. WMP (up to 10%) in replacement of cement can be effectively used in concrete [22,23]. According to Aliabdo et al. and Corinaldesi et al. [24,25], filler effect of WMP in concrete resulted into improved properties. Utilization of WPM in the replacement of cement has positive effects on durability properties [26]. Dense concrete can be prepared using WMP leading to improved resistance to chloride migration, permeation and corrosion [27]. Furthermore, economical and eco-friendly concrete can be produced by utilizing WMP [28,29].

In Pakistan, marble is considered among the top extracted minerals [30]. Pakistan has also gifted with 160 million tons of marble deposits [22,30]. Marble and stone industry has grown rapidly in Pakistan with extraction of 3000 tons of marble in 1960s to approximately 450,000 tons in 1990s [31,32]. Growing industry also raised the amount of generated waste. This waste can pollute the environment [22]. WMP being light weight can be transported through air and causes the contamination of natural reservoirs [24,33]. There is no feasible utilization of marble waste in present situation. Moreover, prolong exposure to environment having marble contaminants can lead to severe health issues [34–36]. Environment having marble effluents was reported as the source of kidney problems [13]. Moreover, WMP is also damaging agricultural lands leading to effect the crop generation [37]. Self-compacting concrete can be prepared by utilizing marble as a filler material [38]. Effectiveness of WMP in improving the durability of concrete was explored by various researchers [31,39]. However, scant research is available regarding the utilization of WMP to control ASR. Focus of this study was to evaluate the effectiveness of WMP in controlling ASR expansion. Utilization of WMP in controlling ASR expansion can overcome the problem along with effective utilization of this abundant waste.

Table 1
Mixture proportions of cement and WMP.

Mixture	Cement (%)	WMP (%)
REF	100	–
WMP10	90	10
WMP20	80	20
WMP30	70	30
WMP40	60	40

2. Experimental program

To evaluate the suitability of WMP in controlling ASR expansion, experimental study was conducted in two phases. In the first phase, chemical and physical properties of raw materials were evaluated. Moreover, mortar mixtures (Table 1) incorporating WMP in various proportions were also prepared to determine the effect of WMP on fresh, mechanical and thermal properties of mortar mixtures. In second phase, role of WMP in controlling ASR expansion was evaluated following ASTM C1260 (Standard test method for potential alkali reactivity of aggregates). Microscopic and chemical behavior of selected specimens in controlling expansion due to ASR was also studied through scanning electron microscopy (SEM) and energy disperse X-ray spectroscopy (EDS).

2.1. Materials

To study the effectiveness of WMP in controlling ASR, WMP in the form of slurry was obtained from the local marble industry located in Pakistan. Slurry was first oven dried at 100 °C for 24 h. Then, dried slurry was ground in a ball mill until all the particles were finer than 45 μm, to be similar to cement particles. The obtained WMP was then used during the study. Local coarse aggregate with dolomite-limestone rock type from Pakistan was used to develop the phenomena of ASR. Dolomite-limestone rock type was observed alkali-silica reactive in previous studies [40,41]. Aggregate was obtained in desired sizes by blasting and wet crushing techniques. During the study, locally available ordinary Portland cement and clean tap water were used.

2.2. Mixture proportions

Cement was replaced with WMP in various proportions (10%, 20%, 30% and 40% by weight) to prepare the mortar mixtures for cubes and bars. Cement to aggregate ratio was kept 1–2.25 to prepare the specimens. Constant (ASTM C1260) and varying water-cement ratios were used to prepare mortar bar specimens. Firstly, ASTM C1260 was followed and water-cement ratio was kept constant i.e., 0.47. For control mixture without WMP, flowability of 110 mm was obtained keeping constant water-cement ratio. However, with increasing proportion of WMP, decrease in flowability was observed. Therefore, mortar mixtures with varying water-cement ratio were also prepared to achieve the constant flow of 110 mm.

3. Test methodologies

3.1. Raw materials

Chemical properties of raw materials (cement and WMP) were analyzed through X-ray fluorescence (XRF) and X-ray diffraction (XRD). However, physical properties of cement and WMP were determined through fineness and specific gravity. Furthermore, autoclave expansion of cement was also determined.

Petrographic examination (ASTM C295-Standard guide for petrographic examination of aggregates for concrete) and chemical test (ASTM C289-Standard test method for potential alkali-silica reactivity of aggregates (chemical method)) were used to determine the chemical composition of aggregate particles. However, aggregate physical properties were determined through water absorption, specific gravity, impact resistance, crushing resistance, abrasion resistance, bulk density, voids content and sulfate soundness.

3.2. Fresh properties of mortar

Different ASTM standards were followed to determine the fresh properties of mortar mixture incorporating WMP in different proportions along with reactive aggregate. For all the mixtures consistency and setting time were determined following ASTM C187 (Standard test method for normal consistency of hydraulic cement) and ASTM C191 (Standard test methods for time of setting of hydraulic cement by vicat needle), respectively. European standard EN 196-3 (Methods of testing cement – part 3: determination of setting times and soundness) was used to determine the property of soundness. ASTM C1437 (Standard test method for flow of hydraulic cement mortar) was followed to determine the workability of mortar mixtures. First, flow was measured keeping water-cement ratio constant i.e., 0.47 (following ASTM C1260). Generally