Sustainable Materials and Technologies 9 (2016) 1–9

Contents lists available at ScienceDirect

Sustainable Materials and Technologies

journal homepage: www.elsevier.com/locate/susmat

Experimental study of concrete made with granite and iron powders as partial replacement of sand

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ARTICLE INFO

Article history:
Received 8 November 2015
Received in revised form 24 April 2016
Accepted 2 June 2016
Available online 16 June 2016

Keywords:
Granite Powder
Iron Powder
Compressive strength
Flexural strength
Sustainability

ABSTRACT

Granite Powder (GP) and Iron Powder (IP) are industrial byproducts generated from the granite polishing and milling industry in powder form respectively. These byproducts are left largely unused and are hazardous materials to human health because they are airborne and can be easily inhaled. An experimental investigation has been carried out to explore the possibility of using the granite powder and iron powder as a partial replacement of sand in concrete. Twenty cubes and ten beams of concrete with GP and twenty cubes and ten beams of concrete with IP were prepared and tested. The percentages of GP and IP added to replace sand were 5%, 10%, 15%, and 20% of the sand by weight. It was observed that substitution of 10% of sand by weight with granite powder in concrete was the most effective in increasing the compressive and flexural strength compared to other ratios. The test resulted showed that for 10% ratio of GP in concrete, the increase in the compressive strength was about 30% compared to normal concrete. Similar results were also observed for the flexure. It was also observed that substitution of up to 20% of sand by weight with iron powder in concrete resulted in an increase in compressive and flexural strength of the concrete.

1. Introduction

Concrete is the single most widely used construction material in the world today. It is used in buildings, bridges, sidewalks, highway pavements, house construction, dams, and many other applications. The key to a strong and durable concrete are the mix proportions between the various components. Less cement paste can lead to more voids, thus less strength and durability while more cement paste can lead to more shrinkage and less durability. The gradation and the ratio of fine aggregates to coarse aggregates can affect strength and porosity. The mix design should also achieve the desired workability of concrete so as to prevent segregation and allow for ease of placement. Typically, a concrete mix is about 10% to 15% cement, 25% to 30% sand, 40% to 45% percent aggregate and 15% to 20% water. Entrained air (5% to 7%) is also added to concrete to improve durability. Concrete should have enough compressive strength and flexural strength to support applied loads. At the same time it should have good durability to increase its design life and reduce maintenance costs [1]. In general, durable concrete will have good resistance to freeze and thaw, abrasion, sulfate reactions, ultraviolet radiation, seawater, alkali-silica reaction, and chlorides. The gradation and maximum size of aggregates are important parameters in any concrete mix. They affect relative proportions in mix, workability, economy, porosity and shrinkage of concrete. Granite powder, a waste material from the granite polishing industry, is a promising material for use in concrete similar to those of pozzolanic materials such as silica fume, fly ash, slag, and others. These products can be used as a filler material (substituting sand) to reduce the void content in concrete. Granite powder is an industrial byproduct obtained from crushing of granite stone and granite stone polishing industry in a powder form. It is also generated from recycling marble tops, terrazzo, granite pavers, and stone scraps and discards. If left on its own and is not properly collected and stored, the fine granite powder can be easily be airborne and will cause health problems and environmental pollution.

Inhalation of granite powder fine particles is a health hazard and is a cause of lung diseases especially for people living near granite mills. In this present work, granite powder is used as partial replacement of sand in concrete in different percentage and the associated compressive strength, flexural, and splitting tensile strengths of concrete have been evaluated. By doing so, natural resources of sand can be preserved and the health hazards of these industrial wastes are minimized.

Recycling of granite dust will prevent these wastes from ending up in landfills and provides affordable, eco-friendly, solid stone for various uses. Recycled tiles made from recycled glass or wastes from mines or factories have been used for floors, countertops, and walls [2]. Ceramic

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http://dx.doi.org/10.1016/j.susmat.2016.06.001
2214-9937/

tiles may be made from factory waste (known as post-industrial waste) generated by the production of conventional tiles. Debris series from fireclay tiles combine post-industrial and post-consumer recycled wastes. The Debris series tile consists of 26% recycled granite dust (post-industrial waste) from a granite cutting operation. It also contains 26% recycled glass (post-consumer waste).

Perez et al. [3] conducted a study on the use of recycled marble tops as partial replacement of sand in concrete. The paper points out that the researchers have analyzed the effect of replacing cement, sand, and coarse aggregate with marble byproduct in many countries, but there is a lack of research analyzing the use of marble waste in the United States. This is especially true for postindustrial byproducts such as countertop installation waste, or postconsumer products after a building deconstruction. They highlight the advantages of using such recycled materials in concrete because of potential cost, regulatory and green certification benefits. In particular, they mention that the cost of delivering waste materials to landfills and the landfills' fees are especially high in localities that have stringent environmental regulations such as the San Francisco Bay Area. Results from their study showed that marble, terrazzo and granite countertop waste from construction finishes activities can be effectively used as a replacement for up to 30% coarse and fine aggregate in concrete without negatively affecting the slump, the 7-day compressive strength or the 28-day compressive strength. The use of such byproducts in concrete, rather than disposing them in a landfill, significantly reduces the impact of such materials on the environment. Their research concludes that the most practical, environmentally friendly, and cost efficient use of the recycled materials (marble, terrazzo and granite) in a project is to be a partial coarse aggregate substitute. According to the Leadership in Energy and Environmental Design (LEED) system developed by the US Green Building Council (USGBC), credits are given for reducing construction and demolition waste disposed in landfills and incineration facilities by recovering, reusing, and recycling materials. In addition, the main cost will be incurred in storing and collecting granite powder and iron powder hazard materials. Thus recycling these materials and using as partial replacement of sand in concrete will be beneficial both environmentally and economically.

Industrial wastes from the steel industry such as iron ore tailings and iron powder wastes from steel production can be hazardous to the environment. Stockpiling this material near production sites can results in soil and ground water contamination. Alzaed [4] evaluated the effects of iron fillings on the compressive and tensile strength of concrete. His results showed that both the compressive strength and tensile strength increased with the addition of iron fillings to the mix. Kala [5] conducted tests on granite powder as a partial sand replacement in high performance concrete and showed the beneficial effects on its mechanical properties. Of all the six mixtures he considered, concrete with 25% of granite powder (GP25) was found to be superior to other percentages of granite powder concrete as well as conventional. Prabhu et al. [6] studied the influence of Foundry Sand in concrete its strength and durability. Their results revealed that compared to the concrete mixtures with a substitution rate of 30%, the control mixture had a compressive strength about 6.3% higher. The results from durability tests of concrete mixtures containing foundry sand up to 30% were relatively close to those of the control mixture. Kumar et al., [7] studied the compressive strength of concrete by replacing cement with ceramic waste and utilizing the same in construction industry. Kumar et al., [8] investigated the effect of using quarry dust as a possible substitute for cement in concrete. They evaluated various concrete mixes with partial replacement of cement with varying percentage of quarry dust (10%, 15%, 20%, 25%, 30%, 35%, and 40%). From the experimental studies, they reported that 25% partial replacement of cement with quarry dust showed improvement in hardened of concrete. Mustafa et al., [9] conducted a review on fly ash-based geopolymer concrete without cement and found that the compressive strength increased with the increasing fly ash fineness and thus reducing the porosity. Also, the fly ash-based geopolymer provided better resistance against aggressive environment and elevated temperature compared to normal concrete. Baboo et al., [10] studied the influence of the marble powder/granules in concrete mix and found an increase in the workability and compressive strength with an increase in the content of waste marble powder/granules. Alzboon et al. [11] studied the effect of using stone cutting waste on the compression strength and slump characteristics of concrete and showed that the treated sludge generated from the stone cutting processes can be regarded as a source of water used in concrete mixes.

One of the most important benefits of substituting granite powder in concrete is on human health. The controlled collection of granite dust from industrial facilities will reduce the amount of silica in the air thus reducing the risk of silicosis [12]. Workers involved in manufacturing, grinding, finishing, and installing natural and manufactured stone and granite countertops are at risk for significant crystalline silica exposure. Studies have shown that workers who inhale very small crystalline silica particles are at risk for silicosis – an incurable, progressively disabling and sometimes fatal lung disease [13]. The US Department of Labor and the US National Institute of Occupational Safety and Health (NIOSH) recommends that employers install and maintain engineering controls to eliminate or reduce the amount of silica in the air and the build-up of dust on equipment and surfaces. Examples of controls include: exhaust ventilation and dust collection systems, water sprays, wet drilling, enclosed cabs, and drill platform skirts. NIOSH recommends that employers control exposure to respirable crystalline silica so that no worker is exposed to a time-weighted average concentration of silica greater than 50 $\mu g/m^3$ of air, as determined by a full-shift sample for up to a 10-h workday of a 40-h workweek. The Occupational Safety and Health Administration (OSHA) permissible limit of pure quartz silica exposure is about 100 $\mu g/m^3$ [13]. Sirianni et al. [14] reported significant differences in particle size distributions in silica content of granite quarries in Vermont depending on the extent of ventilation and the nature and activity of work performed. The researchers concluded that such variability in silica content raises concerns about the adequacy of silica exposure assessment.

Vijayalakshmi et al. [15] evaluated the durability of concrete made with granite powder. They studied durability properties such as water permeability, rapid chloride penetration (RCPT), carbonation depth, sulfate resistance and electrical resistivity. Their results showed that the replacement of natural sand with granite powder (GP) waste up to 15% of any formulation is favorable for the concrete making without adversely affecting the strength and durability. They recommended to chemically bleaching the GP prior to blending in the concrete to increase the sulfate resistance.

Singh et al. [16,17] suggested that 25–40% of river sand can be substituted by the granite cutting waste (GCW) with a favorable influence on the investigated parameters. Their results showed that the optimum amount of GCW to be used in concrete depends on the water-cement ratio of concrete. Singh et al. [18] published a study reviewing past research on replacing sand with granite dust. Their review showed that granite dust has increased the mechanical properties of concrete and has the potential to produce durable concrete. Their review of previous research showed that granite dust concrete exhibits enhanced dense and compact concrete matrix at optimum percentage replacement levels. Zhao et al. [19] studied the use of iron ore tailings in ultra-high strength concrete. Their results showed comparable results between the concrete with iron ore tailing less than 40% and the control concrete.

Results from this study and from studies by others referenced in this introduction showed that there are advantages to concrete when granite powder is used to partially replace sand in the concrete mix. The benefits of using granite powder as partial replacement of sand not only can enhance strength but also preserve the natural resources of sand and also keeps these powder particles from being airborne into the atmosphere causing health hazard to humans, in particular children.