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Sustainable utilization of granite cutting waste in high strength concrete

Sarbjeet Singh*, Ravindra Nagar, Vinay Agrawal, Aditya Rana, Anshuman Tiwari

Department of Civil Engineering, Malaviya National Institute of Technology, Jaipur, Rajasthan, India

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A B S T R A C T

The excessive consumption of river sand as a construction material has led to its acute scarcity. Researchers across the globe have attempted to utilize waste of copper slag, rubber tyre, recycled glass, pond ash, foundry sand, plastic, stone etc. as a partial or complete substitute of river sand in concrete. The present study investigates the feasibility of using granite cutting waste (GCW) as a partial substitute of river sand in high strength concrete based on strength, durability & microstructural attributes. Eighteen concrete mixes were cast at 0.30, 0.35 and 0.40 water cement ratios (w/c) by substituting 0%, 10%, 25%, 40%, 55% and 70% river sand by GCW. The concrete mixes were tested for compressive, flexural strength, abrasive resistance, permeability, water absorption, carbonation, corrosion and microstructure; changes in morphology and hydration were also studied. Test results suggested that 25–40% river sand can be substituted by the GCW with a favourable influence on the investigated parameters. The optimum amount of GCW to be used in concrete depends significantly upon water-cement ratio of concrete.

1. Introduction

Concrete is an extensively used building material across the globe. It has been estimated that the world consumes twenty five billion tonnes of concrete every year (WBCSD, 2015). Indian construction industry has been estimated to consume 450 million cubic metre of concrete each year. It is the second most consumed material after water. Concrete is a heterogenous mixture of cement, aggregates (coarse and fine) and water. Fine and coarse aggregate together form about 65–80% volume of the conventional concrete. Fine aggregates comprise upto 20–30% of the total volume of concrete mix. Generally, river sand is used as fine aggregate in concrete. As per calculations, world consumes 5–7.5 billion tonnes of river sand every year for construction purpose. The sand is mined out from river beds. The excessive consumption of river sand has depleted the river beds and adversely affected the surrounding flora and fauna. The excessive mining of sand has resulted in reduced water storage of stream, lower water tables, unstable substructure of river bridges and eroded river beds.

Thus, authorities in some countries have banned or limited the use of river sand as construction material (Bravard et al., 2013). The limited supply of river sand on one hand and increased infrastructural development throughout the country on the other hand has compelled the researchers and concrete manufacturers to look for other viable alternatives. The Rajasthan high court also imposed a ban on sand mining from river Banas in 2013; however the ban was later lifted and provisional sanction was given due to sand requirement for ongoing Jaipur Metro Project (India Times, 2015). It has become imperative to adopt sustainable practices in construction industry to avoid the excessive damage being incurred to the environment on one hand and achieve economy on the other hand. It has been found that due to the adoption of best available technology (BAT), the maximum total energy savings can be increased (Lu et al., 2013). Studies suggest that industrial waste such as slag, rubber tyre, recycled glass, pond ash, waste foundry sand, plastic waste, stone waste etc. can effectively substitute natural sand in concrete with a positive influence on mechanical and durability performance. Rajasthan is a treasure-trove of dimensional stone in the country. Rajasthan accounts for about 20% national granite production (Indian Minerals Yearbook, 2013). The granite is cut and polished prior to its usage. Cutting and polishing operations generate large amount of cutting and polishing waste. Granite cutting waste (GCW) has become a serious problem in its mining regions throughout the state. The severely affected areas

Abbreviations: GCW, Granite Cutting Waste; w/c, water-cement ratio; BAT, Best Available Technology; SEM, Scanning Electron Microscopy.

* Corresponding author. Tel.: +91 9460420420.
E-mail addresses: sarbjeetsinghsaluja@gmail.com, 2013RCE9021@mnit.ac.in (S. Singh).

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facing the problem of disposal of Granite cutting waste are Jaipur, Jalore, Barmer, Pali, Sirohi, Alwar, Jhunjhunu, Tonk, Ajmer, Bhilwara, Sikar and Udaipur. The sustainable use of GCW in concrete will benefit both stone and construction industry. Thus, a study was undertaken at MNIT Jaipur in collaboration with Centre of Development of Stones, Rajasthan to examine the suitability of GCW in concrete.

In the past decade, lot of studies have been conducted by researchers to investigate the suitability of granite dust as a concrete ingredient. Some studies suggested that granite dust can efficiently replace a part or whole of sand while others claim that a part of cement can also be substituted by it. Williams et al. (2008) observed that concrete mix containing 25% granite dust as a sand replacement demonstrated higher strength. They found that the resistance to water permeation of granite dust concrete was better when 25% and 50% of natural sand was substituted by granite dust. In a study conducted by Joel (2010) incorporation of crushed granite dust (upto 100%) as a replacement of sand improved the workability of concrete. Compressive and split tensile strengths of concrete were also observed to be improving up to 20% substitution (at all testing ages). Divakar et al. (2012) observed increment in compressive and flexural strengths up to 50% and 5% replacement of sand respectively. The split tensile strength exhibited similar behaviour as that of flexural strength. Vijayalakshmi et al. (2013) showed that inclusion of granite powder as a replacement of fine aggregates in concrete reduced the workability. The substitution of 15% sand by granite powder did not affect mechanical properties (compressive, flexural, split tensile strength and modulus of elasticity) significantly. Moreover incorporation of granite powder beyond 15% resulted in degraded mechanical properties. The resistance against carbonation, permeation and chloride ion migration of concrete mixes containing granite powder reduced with the increasing replacements. Adigun (2013) completely replaced sand by crushed granite dust at varying proportions. Increasing replacements of sand by crushed granite dust enhanced the workability of concrete. An improvement in compressive strength was also observed upto 75% replacement level. Nevertheless, strength of granite dust concrete was comparable to control at higher replacement levels. In a similar study, Felixkala and Sethuraman (2013) replaced sand by granite powder at varying proportions (0%, 25%, 50%, 75% and 100%). Slump values increased with increasing replacement levels. An increase in compressive strength was noticed with the incorporation of granite dust, at all testing ages. Substitution of 25% sand by granite dust had a favourable impact on concrete's flexural, tensile strength and modulus of elasticity. Arulraj et al. (2013) observed an increase in compressive and tensile strength upto 20% replacement of sand by granite dust. Mármol et al. (2010) observed that granite slurry can efficiently replace natural sand completely with a positive influence on strength of mortar. On the contrary, replacing cement by granite slurry can be detrimental to strength properties. Elmoaty (2013) observed an increase in compressive and split tensile strengths when 5% and 10% granite dust was used as a replacement and an additive to cement in concrete mixes respectively. Ramos et al. (2013) concluded that 10% superfine granite dust can effectively substitute cement in concrete without any significant strength loss. Li et al. (2013) observed an improvement in strength of concrete mixes formulated with fly ash magnesium oxychloride cement and 10% granite dust content. Balasubramaniam and Thirugnanam (2015) found that upto 10% replacement of manufactured sand by granite powder improves the mechanical property of concrete.

The literature review suggested that the detailed strength & durability studies conducted by different researchers were confined to high w/c ratios ranging from 0.40 to 0.55 and granite powder/dust content. A strong need of a comphrensive study encompassing strength, durability and microstructural aspects was felt for lower w/c ratios. The present study attempts the same for concrete containing GCW as a partial substitute of natural river sand for high strength concrete at 0.30, 0.35 and 0.40 w/c. American Concrete Institute (ACI) defines high strength concrete as a concrete having strength above 41 MPa (ACI, 1992).

2. Experimental programme

2.1. Materials

The Portland cement of 43 grade confirming to BIS 8112-1989 was used in the study. The coarse aggregates of maximum nominal size 20 mm with basaltic origin were used. Banas river sand was used as fine aggregate. GCW was procured from stone processing industry in Shahpura, Jaipur (Fig. 1). River sand and GCW confirmed the zone III and IV (IS 383:1970) of sand to be used for construction purpose. The in-situ water content of GCW was 1–2%. GCW was dried at room temperature for 48 h, prior to its testing. Scanning Electron Microscopy (SEM) images demonstrated that particles of GCW (Fig. 2) are relatively rough and angular than river sand (Fig. 3). The shape and texture of GCW particles might reduce workability but can offer enhanced adherence to cement paste. The elemental composition as determined by Energy dispersive Spectrometer (EDS) of GCW and river sand is shown in Figs. 4 and 5. The elements present in GCW and river sand are similar (O, Si, Al, K and Mg). However, 2.34% sodium (Na) was also detected in GCW. Particle size analysis of different aggregates used in the study is presented in Fig. 6. Physical and chemical properties of different concrete ingredients used are shown in Tables 1 and 2.

2.2. Mixes

In order to determine the effect of partial replacement of sand by GCW on high strength concrete, eighteen concrete mixes were formulated with replacement ratios of 0%, 10%, 25%, 40%, 55% and 70% at 0.30, 0.35 and 0.40 w/c respectively. Detailed mix proportions of different mixes cast is shown in Table 3. Mixes were cast in pan mixer of 100 L capacity. After introducing materials in pan mixer, dry mixing was carried out for three minutes to ensure homogeneity among dry concrete materials. The water was then introduced and mixing was carried out for another four minutes. Just after mixing, fresh concrete mixes were put to slump test.

Fig. 1. Accumulated waste of granite cutting.