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Technical note

Effective utilisation of quartz sandstone mining wastes: A technical note on its thermal resistance

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A B S T R A C T

Sandstones are a sedimentary type of rock which is composed of quartz, feldspar and other minerals. Since quartz and feldspar are the most common minerals in the Earth's crust, they are found in most of the sandstones irrespective of the region they occur. The formation of sandstone results by sedimentation through air or wind followed by the compacting pressure of overlying deposits and cementation by precipitation of minerals. Rajasthan, being the largest state by area in India, is the major sandstone producing region. Although sandstones from the area are extensively used as roofing, flooring and paving material, the process of mining them generates an enormous amount of sandstone wastes. These sandstone wastes with quartz-dominated elemental framework were utilised in an M30 grade concrete with water to cement ratio of 0.35 to overcome the landfilling problems and to reduce the use of depleting conventional coarse aggregates in the Vindhyan regions of Northern India. The concrete samples were investigated by scanning electron microscopy and thermogravimetry. The microscopic study revealed the presence of increased void fractions in the concrete samples containing quartz sandstone aggregates. These void fractions were found to enhance the thermal resistance of concrete based on the reduced weight loss upon heating them and also assumed to improve insulation properties by hindering the heat transfer in the material. The efficient utilisation of these quartz sandstone wastes in concrete can reduce the substantial amount of landfill that is used for dumping them and also provide a valuable source of supplementary aggregate used in the production of cement concrete contributing to the overall sustainability.

1. Introduction

The term sandstone denotes a rock formed by grains which are sand-sized. Quartz sandstones have a framework of about 90% quartz and with the limited amount of some other grains like feldspars and lithic fragments. These quartz sandstones belong to mature or sub-mature types of sedimentary rocks and are usually cemented by silica, which binds the sand-sized grains together. Most of the quartz sandstones exhibit textural and compositional maturity by sedimentology due to various types of sediment transportation. The two most common depositional environments that produce quartz sandstones are shallow sea shore areas i.e. upper shore-face and Aeolian processes. Aeolian process are the wind events that have the capability to shape the surface of the earth which may transport, erode and deposit sediment materials in arid regions. Even though water is the commanding erodible force when compared to the wind, in deserts wind becomes the only transport mechanism which disintegrates sediment materials.

The mode of transport of soil particles during wind erosion is governed by soil particle size (Jia et al., 2015). The moisture content of the soil in these arid regions is less than 10%, and hence it does not prevent erosion of fine particles (Silva et al., 2015). Hence greater amounts of finer particles are transported due to the Aeolian process leading to massive accumulations of sandstone reserves all over the region. Such enormous accumulations of sandstone wastes lead to landfilling problems affecting the overall sustainability of the region (Table 1). Although there are some literature focussing on the types of sandstone and their significant effect on concrete's strength, there is very limited research focussing on thermal effects of concretes containing quartz sandstone aggregates. Northern states of India, like Rajasthan, produce huge amounts of sandstone wastes. The disposal of these wastes is a severe social and environmental problem. The recycling of these

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Table 1
The output of mined out sandstone reserves in Rajasthan, India.

Sandstone Waste Generated (in thousand tonnes)								
Year	1	2	3	4	5	6	7	8
	Mined out Reserves	Mine waste @ 25% of Mine Production (3)	Sandstone Production as per DMG, Rajasthan (As Blocks or Khandas)	Dressing Waste (Lumps - 15% of Block Waste)	Processing Waste + Polishing Waste (Powdered - 25% of Block weight)	Dressing Waste + Polishing + Processing waste	Total Waste	Finished Goods by Weight (1-7)
2001	8233	2058	6175	926	1544	2470	4528	3705
2002	7636	1909	5727	859	1432	2291	4200	3436
2003	9783	2446	7338	1101	1834	2935	5381	4403
2004	11176	2794	8382	1257	2096	3353	6147	5029
2005	9359	2340	7019	1053	1755	2808	5147	4211
2006	10409	2602	7807	1171	1952	3123	5725	4684
2007	11594	2898	8695	1304	2174	3478	6376	5217
2008	13956	3489	10467	1570	2617	4187	7676	6280
2009	18462	4616	13847	2077	3462	5539	10154	8308
2010	15632	3908	11724	1759	2931	4690	8598	7034
2011	18840	4710	14130	2120	3533	5653	10363	8477
2012	21841	5460	16381	2457	4095	6652	12112	9729
2013		−2014	43351	10838	32513	4877	8128	13005
23843	19508							
Total	200272	50068	150205	22531	37553	60184	110250	90021

Data Source, Centre for Development of stones, Jaipur, Rajasthan, India.

wastes as aggregate to produce new concrete can reduce the problem of waste and help the preservation of natural aggregate resources (Peem Nuaklong et al., 2016). The building and construction industry contributes to the increase of carbon emissions level in many aspects, such as manufacturing of raw materials and transportation of finished products (Yun Zhong and Peng Wu, 2015). Also, concrete industry is one of the major sources of consuming the high volume of natural resources (Payam Shafigh et al., 2016). Therefore, for construction to be more cost-effective and environmentally-friendly it could be useful to combine the building of new lightweight structures with the use of a secondary lightweight aggregate source (Jose Alexandre Bogas et al., 2015). On successful utilisation of quartz sandstones, the concrete is expected to have an increased thermal efficiency, cause the less landfilling problem, decrease depletion of natural coarse aggregates whereby contributing to the overall sustainability.

2. Material properties and preparation of test samples

Ordinary Portland cement of grade 43, conforming to IS: 8112 (1989) was used (specific gravity 3.15, normal consistency 32%, initial setting time 66 min and final setting time 164 min). Natural river sand confirming to zone II as per IS: 383 (1970) (void content 34% as per ASTM C 29/C 29M (2009), specific gravity 2.63, free surface moisture content 1% and fineness modulus 2.83). Coarse aggregates, 10 mm size (fineness modulus 6.08) and 20 mm size (fineness modulus 7.22) crushed stone were used as coarse aggregates with an average specific gravity of 2.64. Quartz sandstone coarse aggregate, 10 mm size (fineness modulus 6.04) and 25 mm size (fineness modulus 7.24) were used as partial replacement for coarse aggregates with an average specific gravity of 2.45. The particle size distribution, composition of aggregates, cement properties and gradation details are the same as given in Kumar et al. (2016a,b). The substitution of quartz sandstones were done from 0% to 100% at multiples of 20%. Control mix consists of 0% quartz sandstone and substitution of coarse aggregates was done for 0–100%, in the multiples of 20%.

3. Methodology

The methodology of the observations carried out are as follows.

3.1. Scanning electron microscopic observations (SEM)

Scanning electron microscopic observations are important for finding maturity of sedimentary rocks and also to study the mechanical and durability properties of concrete in detail (Peng et al., 2015). Microstructural specimens were obtained from M30 grade concrete cubes (w/c of 0.35) designed as per IS: 10262 (2010) and IS: 456 (2000). Concrete specimens had quartz sandstone replacements at increasing percentages of 0%–100% with 20% steps. Several studies have found that some of the wastes do not interfere with the hydration process and/or the morphology of hydrated products, thereby making the microstructure present in the interfacial zone denser. Sometimes the concrete prepared with lightweight and porous aggregates such as sandstones are stronger in compression than the gravel aggregate concrete due to enhanced hydration as a result of internal curing (Medina et al., 2012; Erdem et al., 2012). However, excess water beyond the stoichiometric demand for hydration might add to the porosity of the matrix declining the strength gain. Similar penetration studies were done on cement mortars and concrete such as high strength light weight aggregate concrete and metakaolin (Halamickova et al., 1995; Chia and Zhang, 2002; Khatri and Sirivivatnanon, 1997; Boddy et al., 2001; Yang and Cho, 2003; Shi, 2004).

An S-4700 Field Emission Scanning Electron Microscope (FE-SEM) was used to image the concrete samples. On replacement of quartz sandstones in concrete, scanning electron microscope images showed slightly greater porosity and also finer grain structure as moving from the control concrete to those having replacements by quartz sandstone. The increase in porosity may be due to using of sedimentary stone when compared to the control concrete made from magmatic rock aggregate, and sandstone is assumed to absorb more water which in turn leaves gaps between the sandstone and cement paste, as seen by SEM (Fig. 1). The other reason corresponding to the increased porosity is inherited from the formation process of sandstone itself (i.e. sedimentation) resulting in voids within the material.

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