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Case study

Stress-strain characteristics of concrete containing quarry rock dust as partial replacement of sand

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ABSTRACT

The paper presents results of study on concrete using quarry dust to replace sand at levels of 0%, 25%, and 100% by weight. Design mixes were prepared to achieve concrete grades C25, C30, C35, C40 and C45 for each of the three replacement levels. Prismatic specimens were prepared to study the stress-strain behaviour of the concrete. It was observed that the stress-strain curves were similar for all sand replacement levels and that concrete with 100% quarry dust had the maximum strain values. The results of the study showed that for all concrete grades, 25% sand replacement level gave higher (7.9%) modulus of elasticity (MoE) while 100% sand replacement level gave lower (8.6%) MoE relative to 0% sand replacement level. The estimated MoE was compared with values obtained from the formulas proposed by the BS, ACI and IS for estimating the MoE using the compressive strength of concrete. It was found that blending sand and quarry dust produces concrete of enhanced mechanical properties.

1. Introduction

Natural sand has been the conventional fine aggregate in concrete production for many decades. However, there has been extensive research into alternative materials suitable to replace sand in concrete. The need to find replacement for sand stems from the fact that in most parts of the world, there is growing concern about the depletion of sand deposits, environmental and socio-economic threats associated with extraction of sand from river banks, coastal areas and farm lands. Some alternative materials which have been studied for use as partial replacement for sand include fly ash, slag limestone, silica stone, furnace bottom ash and recycled fine aggregate [1–3]. Among the many materials investigated, quarry rock dust (QD) appears to be the most suitable because it is available in large quantities in most parts of the world. The annual production and consumption rate of quarry aggregates in Great Britain and USA is estimated to be 230 million tonnes and 1.73 billion tonnes respectively [4,5]. The use of quarry dust as a building material has been accepted in the advanced countries in the past three decades [6,7]. The level of utilization stems from sustained research work carried out regarding increasing application of quarry fine aggregate.

Studies into the properties of fresh concrete have shown that there is decrease in workability with quarry dust in concrete [2]. The decrease in workability is mostly attributed to high percentage of fines in the quarry dust and also the angular shape and rough texture of the dust particles which result in high water demand.

Investigation into the durability of quarry dust concrete carried out by Ilangovana et al. [6] showed that quarry dust concrete dry shrinkage strains were larger at early ages (below 7 days) but lower at later ages compared with sand concrete. Also, Shanmugavadivu and Malathy [8] reported lower water permeability, chloride-ion penetration, strength and weight loss due to acid-chloride ion attack for concrete with 70% sand replacement with QD. Improved impact resistance of concrete has also been reported [9].

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Table 1
Physical Properties of Aggregates.

Aggregate	Bulk Density (kg/m^3)	Fines Content (%)	Fineness Modulus	Water Absorption (%)	Moisture Content (%)	Specific Gravity	Crushing Value
River sand	1600	3.89	2.66	6.8	3.56	2.66	–
Quarry dust	1650	10.45	3.54	10.6	0.54	2.64	–
Coarse Agg.	1625	–	–	0.54	0.09	2.71	18.3

Studies conducted to investigate the effect of QD on the strength properties of a wide range of concrete grades from C20 to C45 and at varied sand replacement levels showed that the compressive, flexural and split tensile strengths of concrete increased to a maximum at optimum blend of QD and sand. The optimum blend varied greatly from 90:10 to 25:75 (Sand: QD) due to the variability in the properties of materials used for the various studies conducted at different parts of the world. However, in general, an increase of about 8–20% in strength has been reported at optimum sand replacement [2,10–16].

While considerable amount of research has been conducted to study the rheological, strength and durability properties of quarry dust concrete, no work has been carried out on the stress-strain characteristics of concrete with quarry dust. There is therefore the need to study the strength and stress–stress characteristics of concrete with quarry dust.

2. Experimental program

2.1. Materials

Portland limestone cement as the hydraulic binding agent, river sand and quarry rock dust both of 2 mm maximum size as fine aggregate, and 14 mm crushed rock coarse aggregate were used for the concrete. The physical properties of the fine and coarse aggregates are shown in Table 1. The fine and coarse aggregates satisfied the BS 882 [17] specification requirements.

2.2. Mix proportions and preparation of specimens

Three replacement levels of 0%, 25% and 100% quarry dust were used in the concrete mixes. The 25% is the optimum replacement percentage achieved by carrying out strength studies for 0%, 25%, 50%, 75% and 100% sand replacement levels. The respective 28-day strengths were 24.49, 27.91, 24.64, 21.33 and 19.40 N/mm^2 [18]. The mixes were designed to achieve five different target strengths. The concrete mixes were designed to have a near constant slump in the range of 60–180 mm; and as such, the water-cement ratio varied. The procedure used for the mix design was in accordance with that outlined in "Design of Normal Concrete Mixes" [19]. Table 2 shows the detailed mix proportions.

The cement and aggregates were first mixed together in a mixing pan. Water was then added and mixing was continued until a uniform and homogenous matrix was obtained. The mix for each sand replacement level of particular concrete grade was cast in 100 × 100 × 100 mm [20] and 100 × 100 × 200 mm [21] wooden moulds and compacted with a tamping rod in three layers. The specimens were de-molded after 24 hours and cured by immersion in water at a room temperature of 27 °C for 28 days. The prisms were used to obtain the stress–strain curves, and the cubes were used to obtain the compressive strength of the concrete.

Table 2
Mix Proportions of Concrete Mixes.

Mix notation	TCS (N/mm^2)	SRL (%)	w/c ratio	Free water (kg/m^3)	Cement(kg/m^3)	River sand (kg/m^3)	Quarry dust (kg/m^3)	Coarse aggregate (kg/m^3)
RSC25	25	0	0.60	222	370	583	–	1210
RSC30	30	0	0.56	222	397	557	–	1210
RSC35	35	0	0.52	222	427	530	–	1210
RSC40	40	0	0.48	222	463	502	–	1200
RSC45	45	0	0.44	222	505	473	–	1185
SQC25	25	25*	0.60	233	388	517	173	1034
SQC30	30	25*	0.56	233	416	496	166	1035
SQC35	35	25*	0.52	233	448	474	158	1032
SQC40	40	25*	0.48	233	485	451	151	1025
SQC45	45	25*	0.44	233	530	427	143	1012
QDC25	25	100	0.60	240	400	–	789	926
QDC30	30	100	0.56	240	429	–	759	927
QDC35	35	100	0.52	240	462	–	727	926
QDC40	40	100	0.48	240	500	–	695	921
QDC45	45	100	0.44	240	546	–	659	910

TCS is Target characteristic strength; SRL is sand replacement level; 25* is optimum percentage level [18].