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Quarry Dust As A Fine Aggregate Replacement in Concrete Masonry Blocks for Sustainable Construction

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Abstract: Acute shortage of raw materials and their escalating prices together with the unhealthy competition among the manufactures is adversely affecting the sustainability of concrete building blocks now a days. Depletion of natural aggregates and accumulation of construction wastes are other issues challenging the sustainability of construction. Application of quarry dust, the waste material from stone crushing industry as fine aggregate replacement in concrete has practical significance in this regard. This paper investigates the suitability of quarry dust as replacement (10% to 100%) to natural aggregate in concrete masonry blocks. Successful replacement of 30 % can be suggested for load-bearing masonry units with superior strength, comparable durability and better performance in aggressive environments. Suitability of the proposed blocks in structural masonry as well as sustainable construction was also verified.100% replacement of quarry dust was also found suitable for load bearing masonry units with comparable strength and durability characteristics.

Keywords: Quarry dust, concrete building blocks, fine aggregate replacement, sustainable construction, structural masonry

1. Introduction

The widespread availability of concrete building blocks in most areas and the relative affordability of using them in construction projects have contributed to their recent surge in popularity. Meanwhile, the commercially available blocks' strength and longevity is a serious issue. These issues, along with others related to sustainability, are exacerbated by the intense competition between regional producers and the shortage of natural materials. Since natural resources have been mined to exhaustion, there are now serious environmental and legal constraints on the availability of traditional aggregates. Between 40 and 50 billion metric tonnes of sand are mined from quarries, mines, rivers, coasts, and the ocean each year. Around fifty percent of this is used in building and construction (Beiser, 2019).

There are disposal concerns and related environmental impacts with the 200 million tonnes of crushed stone dust (quarry dust) produced annually in India (Patanwadia et al., 2018). Researchers who tested quarry dust as a fine aggregate alternative for concrete found that it increased strength and durability while decreasing workability. Several studies have shown that quarry waste can be used as a 100% substitute for fine aggregate in concrete without compromising the strength of the finished product across a variety of concrete strengths (Ilangovana et al., 2008; Manasseh, 2010; Kannan et al., 2014; Shyam Prakash et al., 2016; Fayaz et al., 2017). Furthermore, all replacement percentages of quarry dust concrete showed long-term strength improvements (Shyam Prakash et al., 2016; Lohani et al., 2012; Kapgate et al., 2013). Researchers found that the maximum strength of concrete at different replacements varied from 10% to 60%,

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depending on the concrete grades, the physical properties of the aggregates, and the resulting differences in workability (Sakthivel et al., 2013; Manasseh, 2010; Ameh et al., 2015; Lohani et al., 2012; Kapgate et al., 2013; Patanwadia, 2018; Fayaz et al., 2017; Shyam Prakash et al., 2016; Vijayakumar et al., 2015; Balamurugan and Perumal,2013; Kannan et al., 2014). According to Kapgate et al. (2013), the presence of a higher content of fines in the quarry dust contributed to enhanced strength qualities by improving the cohesiveness of the concrete. The importance of admixtures in connection to the strength is demonstrated by research by Ilangovana et al., (2008) at greater replacement levels (up to 100%), despite the grade of concrete. Researchers also established the possibility of quarry dust as a fine aggregate replacement in concrete for low strength applications without the use of admixtures and workability concerns. In a 2014 study, Sureshchandra et al. found that quarry dust may successfully substitute up to 50 percent of the cement in load-bearing masonry units while maintaining the same level of strength. Moreover, it was discovered that water absorption rose along with the number of replacements (Ilangovana et al., 2008; Lohani et al., 2012). In addition to these benefits, Ilangovana et al. (2008) noted that quarry rock dust concrete had lower permeability and similar values in shrinkage strains compared to regular concrete. It has also been found that quarry dust concrete performs better in an acidic (H2SO4) and sulphate environment.

In light of the aforementioned, the purpose of this study is to investigate the viability of using quarry dust as a fine aggregate replacement in concrete blocks. The material's applicability to structural masonry and eco-friendly building practises also needs to be explored. Concerns about pollution, rising prices, and a lack of materials are explored in this study of current problems in the building sector.

2. Materials and Methods

The materials utilised in this investigation were regular portland cement (IS 4031-1988 and IS 8112-1989), river sand (IS: 383-1970), 10 mm broken stones (IS: 383-1970), and quarry dust (IS: 383-1970). The physical parameters of river sand, quarry dust (QD), and coarse aggregate (CA) are listed in Table 1, and their particle size distributions are shown in Figures 1, 2, and 3, in that order. Sand aggregates were found to be zone II graded, while aggregates made from quarry dust were graded as zone III. Table 2 displays the results of an XRD examination of fine aggregates' chemical and mineralogical properties.

Table 1 - Physical properties of aggregates

Sl.no	Properties	Aggregates		
		River sand	Quarry dust	6mm Aggregate
1	Specific gravity	2.54	2.758	2.79
2	Bulk density (kg/m^3)	1452	949	1433
3	Porosity	0.428	0.656	0.487
4	Void ratio	0.748	1.907	0.949
5	Fineness modulus	2.686	2.026	5.73

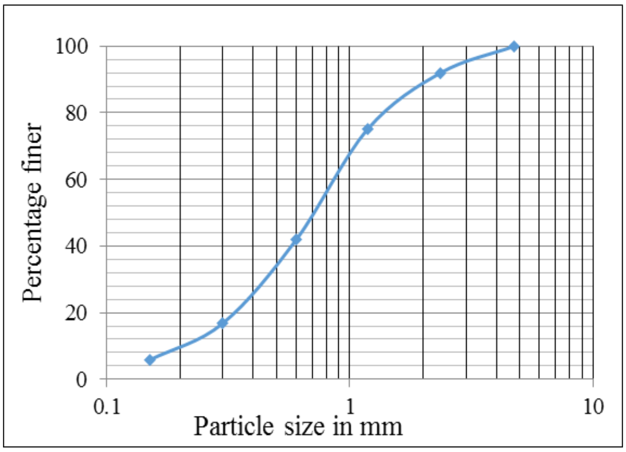

Fig. 1 - Particle size distribution of river sand

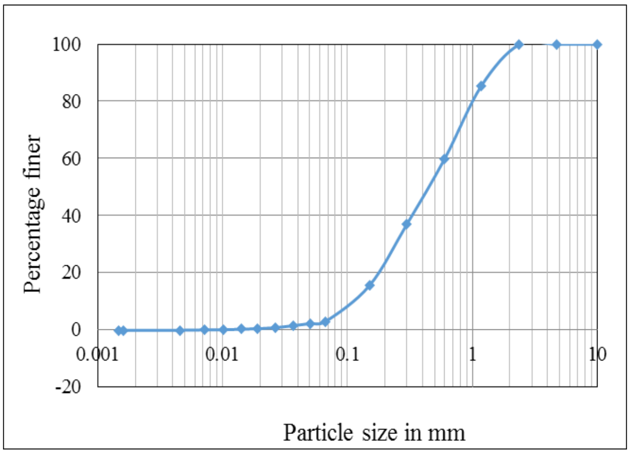

Fig. 2 - Particle size distribution of quarry dust

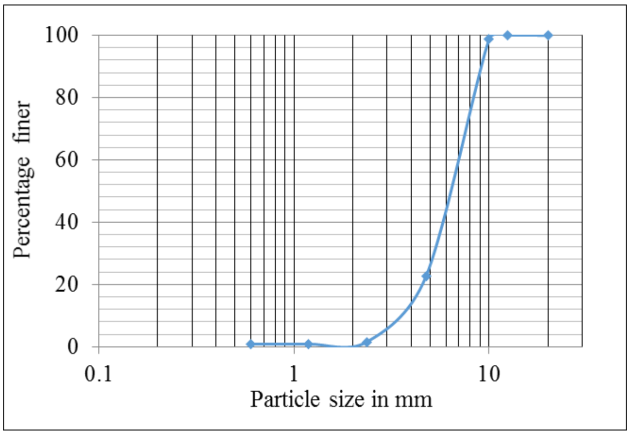

Fig. 3 - Particle size distribution of coarse aggregates

Table 2 - Chemical composition of fine aggregates

Chemical properties	River sand (%)	Quarry dust (%)
Silicon dioxide, SiO_2	80.3	23.9
Anorthite, sodian $Ca_{0.64}Na_{0.35}(Al_{1.63}Si_{2.37}O_8)$	-	73.2
Chabazite-Ca, $Ca_2Al_4Si_8O_{24}(H_2O)_{13}$	11.2	-
Ferric oxide, Fe_2O_3	4.8	2.9
Sylvite, KCl	2.7	-
Halite, NaCl	1.0	-

Mix optimization, tests for concrete building blocks and structural masonry are presented along with a discussion on sustainability characteristics.

2.1 Mix Optimization and Testing

Trial mixes (1:4:8) were prepared for different water-cement ratios (0.45, 0.48 and 0.50) as per IS standards and slump tests were conducted. Figure 4 shows the variations in slump values against the percentage of quarry dust as fine aggregate replacement. Mixes with low water binder ratios (0.45 and 0.48) were found less workable owing to the higher water requirement of quarry dust.

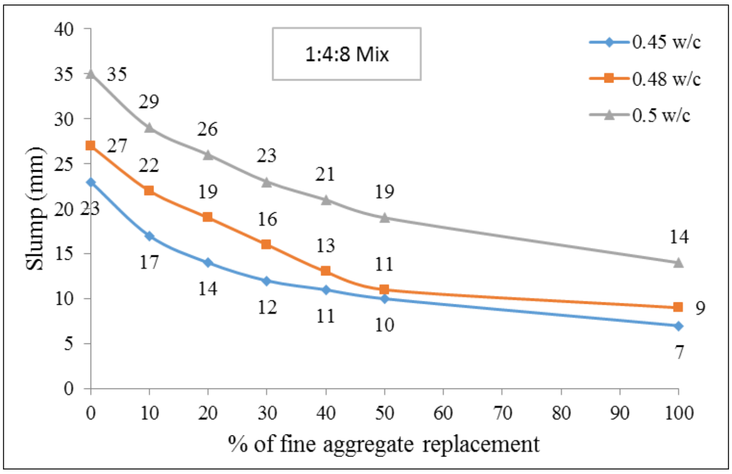

Fig. 4 - percentage of fine aggregate replacement v/s slump value

Taking into account its workability for block production, a mix with a water-cement ratio of 0.50 was chosen for further experiments, and mixes were developed for various substitutes. Compressive strength, density, and water absorption tests were performed on cube specimens (150mm x 150mm x 150mm) in accordance with IS 516-1959. Table 3 displays the results of the tests conducted on the various mixtures.

Table 3 - Details of mixes & Test results

Mix designation	% Replacement	Weight of materials for 1m^3				28th-day Compressive strength (N/mm^2)	Density (Kg/m^3)	Water Absorption (%)
		Cement (Kg)	Sand (Kg)	QD (Kg)	CA (Kg)			
QC00	0	186.29	745.16	0.00	1490.32	5.48	2089	7.584
QC01	10	186.73	672.23	74.69	1493.84	7.72	2169	7.649
QC02	20	187.17	598.94	149.74	1497.36	8.67	2206	7.887
QC03	30	187.62	525.34	225.14	1500.96	9.15	2229	8.037
QC04	40	188.07	451.37	300.91	1504.56	7.94	2166	8.438
QC05	50	188.52	377.04	377.04	1508.16	6.44	2111	9.177
QC010	100	190.80	0.00	763.20	1526.40	5.13	1944	9.301

The specimens' compressive strength was shown to increase up to 30% fine aggregate replacement with quarry dust before dropping further. Density shifts of a similar nature were also reported. However, the presence of small particles in the quarry dust was observed to increase water absorption as the proportion of replacement increased. The 100% replacements group showed similar strength features. Blocks were made of each potential blend, and elementary tests were run on them.

2.2 Block Making and Tests

Using a hydraulic block manufacturing machine (5hp, No 830, Nova engineering), we were able to cast concrete blocks with exact dimensions of 400 x 200 x 150 millimetres, which were then cured in a water tank for 24 hours in the production yard. Several tests were performed on the blocks at predetermined curing times according to IS 2185 (Part 1):2005. Table 4 displays the names of the blocks and the outcomes of the tests.

Table 4 - Compressive strength, Density and Water absorption of blocks (1:4:8 mix)

Mix designation	w/c ratio	Fine aggregate Replacement with Quarry dust	Compressive strength (N/mm^2)		Density (Kg/m^3)	Water Absorption (%)
		% Quarry dust	28days	90days		
QB00	0.50	0	5.18	6.19	2168	7.81
QB01	0.50	10	5.46	6.77	2238	7.87
QB02	0.50	20	5.99	7.16	2271	8.13
QB03	0.50	30	6.38	7.48	2286	9.15
QB04	0.50	40	5.59	6.63	2223	9.72
QB05	0.50	50	4.69	5.73	2140	9.85
QB010	0.50	100	4.11	4.93	2009	9.97

Variations in the test results are consistent with those found in the mix design. The results showed that compressive strength increased up to 30% replacement, then decreased. As a result, QB03 became the preferred candidate for additional testing. Absorption rate (ASTM C67/C67M-20), thermal conductivity (ASTM D 7340-07), and performance after being exposed to chemicals were all studied. Long-term (up to 120 days) exposure of blocks to an acidic environment (H2SO4 - 3% concentration) and an alkaline environment (NaOH -3% concentration) was examined for performance according to Sahoo et al., 2017.

The suggested blocks were tested with a prism according to ASTM C 1314-12 to determine if they were suitable for use in structural masonry. Cement mortar (1:6, 16 N/mm2) was used to build prisms (h 650 mm, t 200 mm), with a maximum mortar thickness of 10 mm and a height to thickness (h/t) ratio of 3.25. According to IS: 1905-1983, the same mortar was also used for capping. After curing for 28 days, compression tests were performed on prism samples. Both the masonry's efficiency and modulus of elasticity were measured. Table 5 displays the findings.

3. Results and Discussions

A discussion on the results of different tests are presented under strength characteristics, durability characteristics and performance characteristics. Suitability of the proposed blocks in structural masonry is also discussed.

3.1 Strength Characteristics

Fig.5 shows the variations in compressive strength for different replacement levels of fine aggregate for different periods. Long term strength gain can be observed for all replacement levels as reported in earlier studies (Shyam Prakash et al., 2016; Lohani et al., 2012; Kapgate et al., 2013). Whereas, an improvement in strength can be noticed for proposed blocks against control blocks only up to 40% replacement of fine aggregate. However, on further increasing the replacements (even at 100%), even though strength reduction was noticed, blocks were found to have strength characteristics suitable for load bearing masonry units satisfying IS 2185 (Part 1):2005.

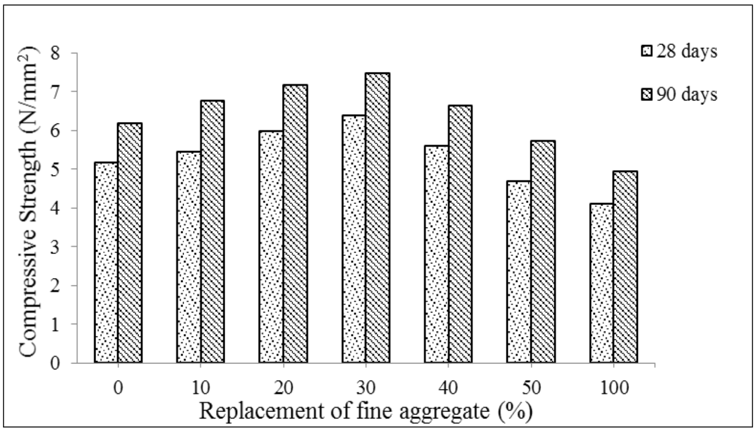

Fig. 5 - Comparison of Compressive strengths for different periods

In addition, blocks with 30% replacement showed the greatest compressive strength. Density also varies in a similar fashion (Fig. 6). This occurs because quarry dust particles act as filler while being incorporated into the blend. Densification of the mixture and strength enhancements are the effects of finer dust particles getting packed in between the interfaces of aggregates and reducing the entrapped air. The non-homogeneity of the mix caused by the presence of extra fine particles in the quarry dust leading to segregation reduces strength and density after 30% replenishment. Lohani et al. drew analogous conclusions (2012). An insufficient amount of cement paste for creating a successful bond with excess fine aggregate can also cause a decrease in compressive strength when used in conjunction with a higher replacement level (Ameh et al., 2015). If the particles don't stick to the matrix as well, the matrix's strength can decrease.

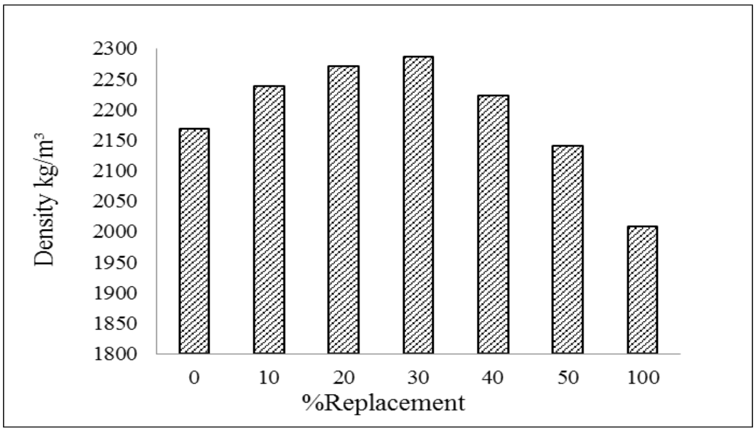

Fig. 6 - Density v/s Percentage replacement of fine aggregate

3.2 Durability Characteristics

The strength of the blocks is measured by how much water they can hold and how quickly they absorb water initially. Previous research by Ilangovana et al., (2008) and Lohani et al., (2010) found that the water absorption of quarry dust concrete blocks increased with increasing percentages of quarry dust substitution (Fig. 7). (2012). Increases in water absorption were observed, but were still well within the parameters set by IS 2185 part-I 2005. Quarry dust particles are more porous and have a higher void ratio than river sand, which may explain why they are more suitable for this purpose. Figure 7 shows the water-absorption pattern, which provides information about the aggregate packing and matrix uniformity at different replacements. In the ranges from 20% to 30% and 30% to 40%, water absorption dramatically shifts. With lower replacements up to 20%, water absorption follows a pattern that indicates the requirement for extra fine particles to fill all the spaces between the cement paste and the aggregate particles. Compressive strength and density readings at 30% replacement are more in line with this theory than those at lower replacements. However beyond 30%, water absorption increases from 30% to 40% and keeps going up because there are more dust particles in the matrix than are needed to fill the spaces between the cement paste and the aggregate particles.

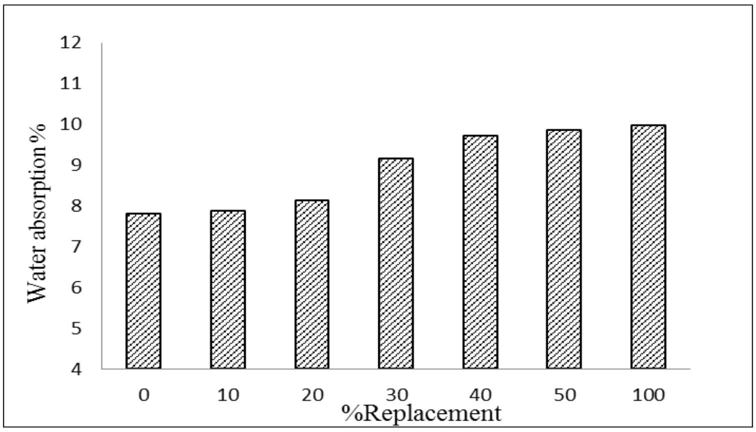

Fig. 7 - Water absorption v/s percentage replacement of fine aggregate

The increased porosity and resulting alterations in the capillary action of the proposed blocks are evidenced by their faster initial absorption rates than QB00 (0.812 Kg/m2/minute vs. 0.670 Kg/m2/minute). The control block units have a lower value than normal because the matrix has discontinuous pores as a result of the uniform gradation of fine particles. Both blocks measured up to expectations established by ASTM C67-86.

3.3 Performance Characteristics

The blocks' thermal conductivity and behaviour when exposed to a chemical environment are described, along with other performance aspects. According to Lee's disc approach, the proposed blocks have somewhat higher thermal conductivity values (0.34 Wm-1K-1) than the control block (0.26 Wm-1K-1) due to the density of their matrix. Both blocks met the standards set forth in International Standard (IS) 2185 (Part 3) -1984.

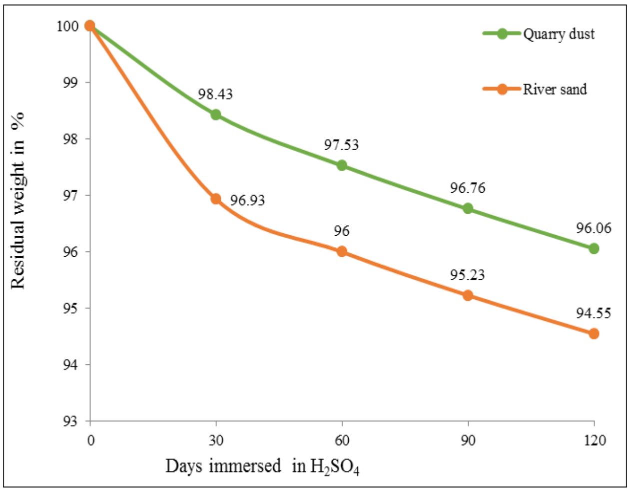

Fig. 8 - Effect of H_2SO_4 on Weight of the Blocks

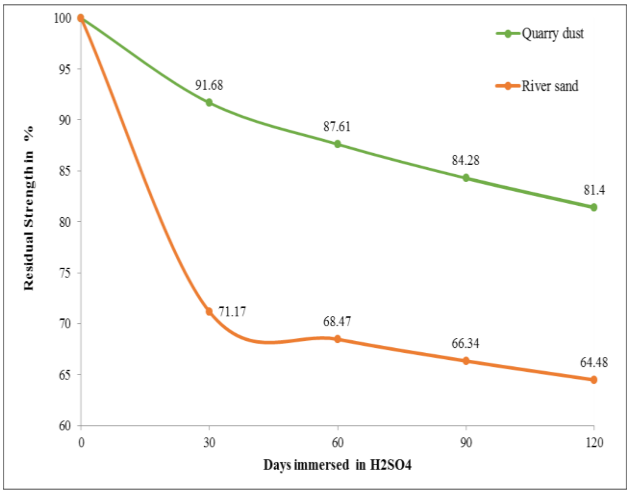

Fig. 9 - Effect of H_2SO_4 on Strength of the Blocks

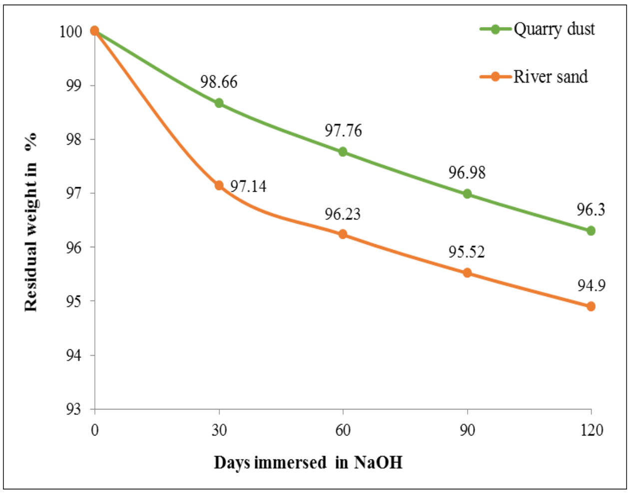

Fig. 10 - Effect of NaOH on Weight of the Blocks

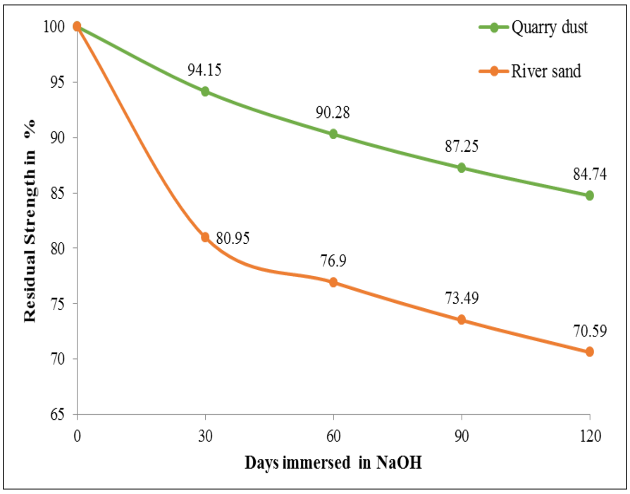

Fig. 11 - Effect of NaOH on Strength of the Blocks

Fig. 8 to Fig. 11 shows the comparison in the variations of residual weight and strength of both the types of blocks for long term exposure to acidic (3% H_2SO_4) and alkaline (3% NaOH) environment. On both occasions, Ilangovana et al., 2008 found that the recommended blocks performed better. The production of calcium silicate hydrate in an H2SO4 environment causes river sand to produce inferior control blocks compared to quarry dust (Shetty, 2008). Alkaline conditions exhibited a similar pattern of behaviour. The poorer (reticular) micro-texture and more porous cement paste formed by the NaOH-silica reaction contribute to the blocks' degradation (Smaoui et al., 2005).

3.4 Suitability of The Proposed Blocks in Structural Masonry

Masonry strength of the prisms showed similar variations with respect to corresponding block strength and satisfies the strength requirement as per IS 1905-1987 with better performance for proposed blocks (Table 5).

Table 5 - Strength characteristics of Structural Masonry

Block Masonry	Size (mm)			Masonry strength (N/mm^2)	Correction factor	Normalized strength (N/mm^2)	Block strength (N/mm^2)	Masonry efficiency (%)
	L	B	D					
Control block masonry	400	200	650	3.88	1.09	4.23	5.18	81.66
Quarry dust block masonry	400	200	650	4.60	1.09	5.01	6.38	78.53

Fig. 12(a) and 12(b) shows the failure pattern of the prisms with visible cracks on the blocks owing to the lower strength of the blocks compared to the strength of the mortar.

Fig. 12 - (a) QB00 Prism failure pattern (b) QB03 Prism failure pattern

Fig.13 shows the stress-strain relationship of both the blocks with a linear variation. Prisms were able to withstand higher loads even after initial cracks, confirming the ductility of the masonry as observed in the stress-strain relationship and failure pattern. Relatively higher E values observed for QB03 masonry can be justified with the block strength of the blocks.

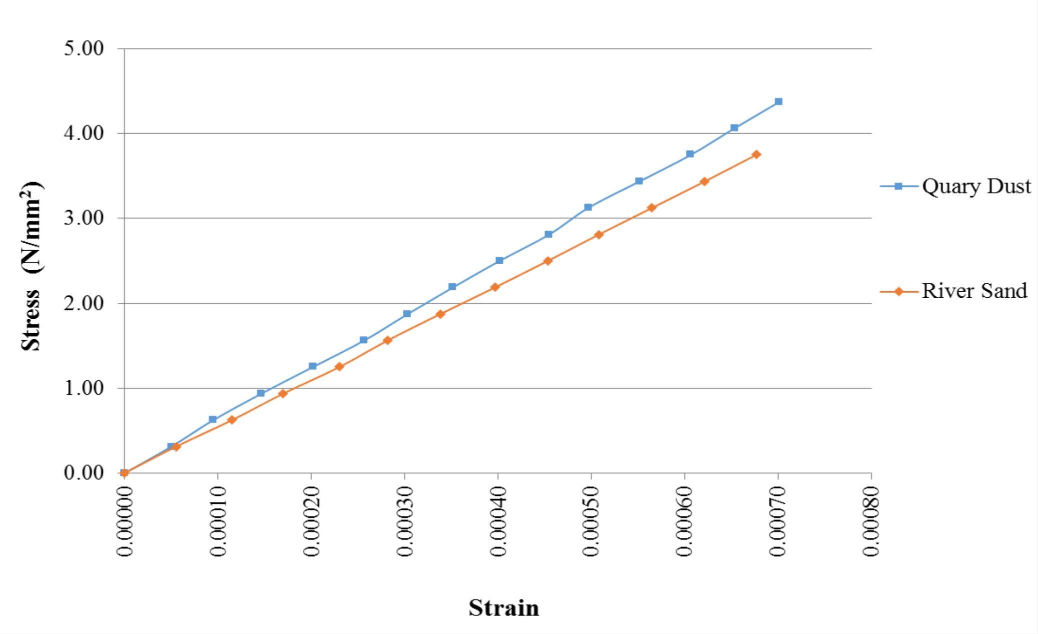

Fig. 13 - Stress-Strain relationship – QB00 and QB03 prisms

4. Suitability of the Proposed Blocks for Sustainable Construction

The suggested blocks are assessed for their viability in sustainable building in terms of environmental, technological, and economic sustainability.

The proposed blocks have better environmental sustainability than traditional concrete blocks since they use fewer resources while yet producing the same or better results. Waste from the building sector, known as quarry dust, poses significant disposal challenges and health risks to the surrounding ecosystem. Hence, the use of quarry dust in masonry blocks improves ecological conditions. Using quarry dust instead of river sand, the extraction of which can have severe environmental effects, improves resource efficiency.

The mechanical properties of the building blocks provide a basis for assessing the long-term viability of the technology. The proposed blocks have greater strength characteristics (by 23%) and equivalent durability characteristics (when compared to the control blocks). It was also discovered that the blocks performed exceptionally well in both acidic and alkaline conditions.

Because it could partially replace the precious river sand, the proposed blocks scored higher economically as well as in other categories of sustainability. So, the commercial production of blocks can expect a significant decrease in cost.

5. Conclusion

The construction industry currently faces significant issues with regards to long-term sustainability, including the overexploitation of natural resources, rising costs, and the accumulation of industrial wastes and their impact on the environment. In order to combat these issues, this study proposes replacing some of the natural aggregates in concrete block masonry with quarry dust. In light of this, we can draw the following conclusions.

- For load-bearing masonry components with comparable strength and longevity, quarry dust can be used as a one-to-one replacement.
- The proposed blocks, which substitute some of the river sand with quarry dust (up to 30 percent), have better strength, durability, and performance than existing alternatives. Suggestions for load-bearing masonry units suited for structural masonry have been found to be successful.
- • Suggested blocks were deemed suitable for sustainable construction due to their improved performance in environmental, technological, and economic sustainability.

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