Original Article

Optimizing Cement Quarry Dust Ratio in Concrete Asphalt Using for Industrial Purposes

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Abstract

Scarcity and the high cost of natural river sand due to government restrictions are the major problems for the construction industry. It was observed that cement quarry dust ratio is higher in quarry dust concrete mixes compared to conventional concrete mixes used for highway projects due to the effects influenced by shape, surface & content of micro fines of quarry dust. In this study, the cement quarry dust ratios were optimized to obtain the optimum strength, workability & to use quarry dust concrete using for industrial purposes. Workability, compressive strength tests were conducted on basic three quarry dust concrete grade mixes which vary quarry dust ratio percentage from 0.41 to 0.43 according to the British design approach. Workability of designed M20, M30 & M40 quarry dust concrete mixes has shown lower workability & compressive strengths on M20 0.41 and 0.42 grade quarry dust concrete mixes were higher compared to conventional concrete mixes. Cost analysis indicates that the percentage of cost reduction on optimized cement quarry dust ratio concrete mixes stands between 27% to 31% than conventional concrete mixes. It can be concluded that M20 – 0.41 and M20 – 0.42 QD concrete mixes can be used for industrial purposes as a replacement for conventional concrete mixes & using superplasticizer, M30 grade quarry dust concrete mixes and M40 – 0.41 quarry dust concrete mix can be used for industrial purposes with enhancing the workability and compressive strength than conventional concrete mixes. Further, it is concluded that optimized cement quarry dust ratio concrete mixes are cost-effective compared to conventional concrete mixes.

***Keywords:* Concrete, Quarry dust, Compressive strength**

Introduction

Demand for concrete is increasing sharply due to the ongoing boom of the building sector & other construction sectors in the world. According to the Hyginus E. Opara *et al.*, (2018) concrete is produced 15 billion tons in the world annually & this production volume consumes a huge number of natural resources for cement & aggregate production.

Due to the sand mining activities, changing the shape & form of the channels, degrading the quality of drinking water, erosion of the river banks, enlarging river mouths can happen. These changes lead to intrusion of saline water of the sea & it will be a threat to the drinking water, bridges & nearby structures. Government restrictions & scarcity of the river sand affect the price of the sand & it increases the cost of construction. As a solution for these problems, replacements of natural sand are used as fine aggregates in concrete.

For the express highways projects in Sri Lanka quarry dust is the main material using for concrete asphalts & all the prior approvals are taking for the quarry dust. So, in Sri Lanka quarry dust is manufactured purposely to use as a replacement for natural sand.

According to RWCN Rajapaksha and HP Sooriyaarachchi (2009) quarry dust has an angular shape with a rough surface texture compared to sand, angular shape creates a more void volume. Due to the higher amount of micro fines water absorption of QD concrete mixes is higher than to the NS concrete mixes. So, because of these reasons, it has been found cement quarry dust ratio is higher in concrete asphalts using for industrial purposes. According to Eng. Kapila Peiris, Project Manager of Olympus Construction (Pvt) Ltd in proposed central expressway project, cement quarry dust ratio in QD concrete mixes is higher compared to NS concrete mixes. High cement quarry dust ratio is not economical for mass construction projects & it damages the environment & caused air pollution due to higher cement production.

In this study aims to identify the optimum cement quarry dust ratio in concrete asphalt using for industrial purposes. The main objectives of this study are to study whether quarry dust satisfies the requirements & the recommendations of the BS standard, to identify the strength & workability of prepared QD concrete mixes compared to control QD & NS concrete mix samples.

Methodology

A. *Materials*

Following materials were used for this study.

1. Cement: Ordinary Portland cement (Strength class 42.5 N) which is compatible with natural sand, quarry dust & sea sand complying with BS EN 12620:2013 was used.
2. Quarry dust: Quarry dust was collected from the local construction site at the respective quarry dust crushing plant. Bulk relative density of quarry dust was taken as 1720 kg/m^3, specific gravity as 2.54 & water absorption as 1.20%.
3. Coarse aggregate: Natural granite aggregate, 20mm aggregate size was taken as the course aggregate which has the density of 2700 kg/m^3, specific gravity as 2.60 & water absorption as 0.45%.
4. Water: Adequate consumable water is used for the concrete mix proportions following the BS 3148 standard.
5. Admixtures: Although for QD concrete mixes Super-plasticizers have been used commercially to increase the workability of quarry dust concrete, for this study any admixtures were not used.
6. Mix designs: For quarry dust as fine aggregate in concrete production there is no standard method for designing. According to R.Ilangovana *et al*., (2008) using BS standard, NS concrete mixes were designed first & then QD concrete mix was designed.

Grade of concrete	**Mix design method**	**Mix proportion**	**Mix proportions (By weight)**
M20	British	M20 - 0.41	0.96:3.47:4.05
		M20 - 0.42	0.87:3.56:4.05
		M20 - 0.43	0.79:3.64:4.05
M30	British	M30 - 0.41	0.79:3.36:4.05
		M30 - 0.42	0.71:3.44:4.05
		M30 - 0.43	0.63:3.52:4.05
M40	British	M40 - 0.41	0.76:2.87:3.37
		M40 - 0.42	0.69:2.94:3.37
		M40 - 0.43	0.62:3.01:3.37

Table I: Designed concrete mixes &their proportions

B. *Test Procedure:*

1) *Particle size distribution of the quarry dust*

Sieve analysis test was done using quarry dust & natural sand according to the BS 882 standard. BS sieves were arranged in order (10mm, 5mm, 2.36mm, 1.18mm, 600µm, 300 µm, 150 µm). Using the sieve sizes & percentage mass passing data a graph was plotted on a semi-log graph sheet as shown in fig.1.

2). *Workability*

Slump test was done using the fresh quarry dust concrete & it was filled into the slump cone in three stages & compacted well. Finally, slump was measured.

3). *Compressive Strength Test*

For the compressive strength test, each above-mentioned mix proportions of quarry dust fresh concrete were filled to 150 × 150 × 150mm moulds. Then cured hardened concrete cube specimens were tested & using maximum axial load & load acting area compressive strength was calculated.

$$\sigma = \frac{F}{A}$$

Where,

σ = Compressive strength (MPa)

F = Maximum axial load applied on the cube (N)

A = Area of the cross-section of the cube (mm^2)

RESULTS AND DISCUSSION

A. Properties of Raw Materials:

1. Particle Size Distribution of the Quarry Dust

According to the gradation curve of quarry dust with upper & lower boundaries, it can be seen that the quarry dust sample fulfilled the recommendations of BS 882 for particle size distribution for fine aggregates.

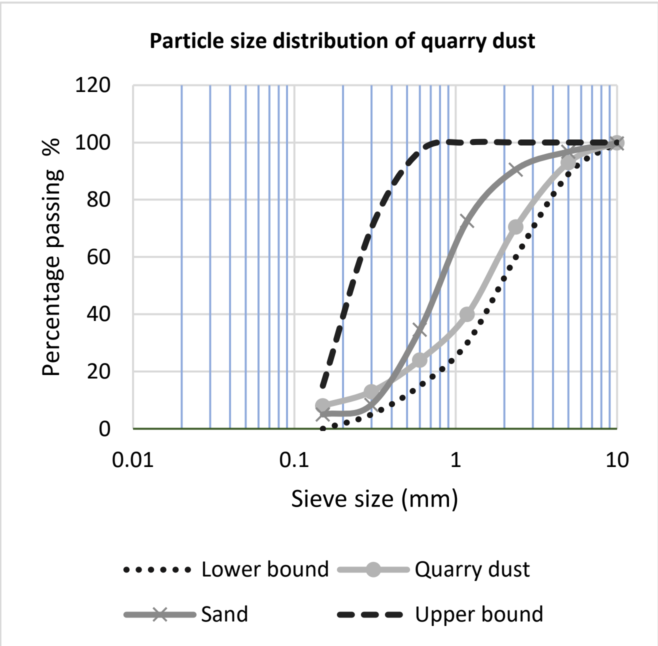

Fig. 1: Practical size distribution of quarry dust

Mix proportion	W/C ratio	QD/C ratio	Slump (mm)	Compressive strength (MPa)		
				7 days	14 days	28 days
M20 - 0.41	0.66	3.61	60	17.71	19.98	25.3
M20 - 0.42	0.60	4.09	55	17.35	21.02	24.9
M20 - 0.43	0.55	4.60	15	15.27	19.33	20.3
M30 - 0.41	0.52	4.25	25	17.62	21.68	26.73
M30 - 0.42	0.46	4.85	20	14.97	17.81	22.95
M30 - 0.43	0.41	5.59	10	16.43	21.46	25.97
M40 - 0.41	0.43	3.78	25	19.74	25.69	31.89
M40 - 0.42	0.39	4.26	15	18.04	19.59	24.37
M40 - 0.43	0.35	4.85	5	11.99	13.20	19.02

Table II : Details of the concrete mix proportions & test results

B. Fresh properties of concrete:

1. Workability of M20, M30 & M40 grade QD concrete mixes

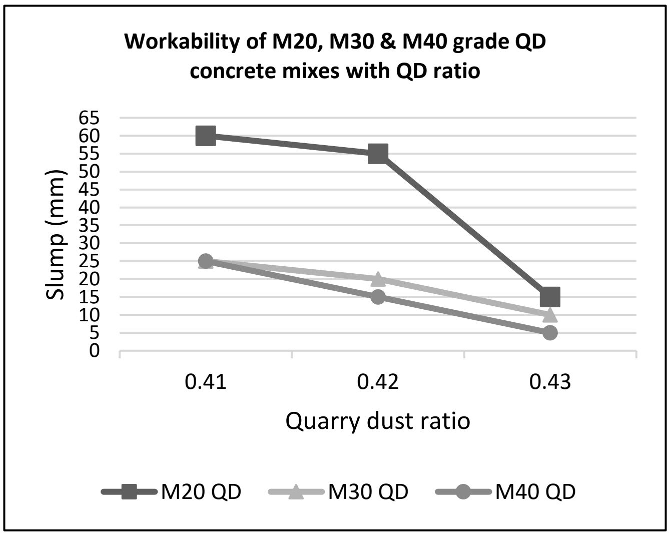

Fig. 2: Workability of M20, M30 & M40 grade QD concrete mixes with QD ratio

M20 – 0.41 QD concrete mix which has the highest water-cement ratio in M20 grade QD concrete mixes showed the highest workability compared to other M20 concrete mixes. A slight reduction was observed in M20 – 0.42 QD mix & sharp reduction was observed in M20 – 0.43 mix.
M30 – 0.41 QD concrete mix which has the highest water-cement ratio in M30 grade QD concrete mixes showed the highest workability compared to other M20 concrete mixes. A slight reduction was observed in M20 – 0.42 QD & M20 – 0.43 mixes.
M40 concrete mixes had the lowest water-cement ratios & higher cement quarry dust ratios & M40 mixes showed the lowest workability compared to other M20 & M30 QD mixes. M40 – 0.43 showed 5 mm slump & it was an 80% sharp decrease than M40 – 0.41 mix. M40 NS control concrete mix has shown a 40 mm slump value & it was a 37.5% increment than M40 – 0.41 quarry dust concrete.

According to R.Ilangovana et *al*., (2008) M20 – 0.40 QD concrete mix with superplasticizers has shown 80mm workability, M30 – 0.38 QD mix has shown 70mm workability & M40 – 0.38 QD mix has shown 30mm workability.

The angular shape, rough surface texture & high silt content quarry dust with the highest cement content could be affected to workability QD concrete mixes when increased the quarry dust proportion.

C. Hardened Properties of Concrete:

1. Compressive strengths M20 grade QD concrete mixes.

It can be observed that the M20 – 0.41 QD concrete mix showed increment at all ages compared to the NS control concrete mixes. M20 - 0.41 QD concrete mix showed 17.71 N/mm^2, 19.98 N/mm^2 & 25.3 N/mm^2 compressive strength value at 7, 14 & 28 days where as control concrete mix showed 13.5 N/mm^2, 18 N/mm^2 & 24 N/mm^2 strength values.

It can be seen that the compressive strength values of M20 – 0.42 QD mixes were lower than M20 – 0.41 QD concrete mixes although it showed increment at the all-ages compared to the NS control concrete mix. M20 - 0.42 QD concrete mix showed 17.35 N/mm^2, 21.02 N/mm^2 & 24.9 N/mm^2 compressive strength value at 7, 14 & 28 days where as control concrete mix showed 13.5 N/mm^2, 18 N/mm^2 & 24 N/mm^2 strength values.

M20 – 0.43 was the concrete mix that had the maximum quarry dust ratio in M20 grade QD mixes. It can be observed that M20 – 0.43 QD concrete mix showed increment at 7 & 14 days. But compressive strength at 28 days was reduced than NS control concrete. M20 - 0.43 QD concrete mix showed 15.27 N/mm^2, 19.33 N/mm^2 & 20.3 N/mm^2 compressive strength value at 7, 14 & 28 days where as control concrete mix showed 13.5 N/mm^2, 18 N/mm^2 & 24 N/mm^2 strength values.

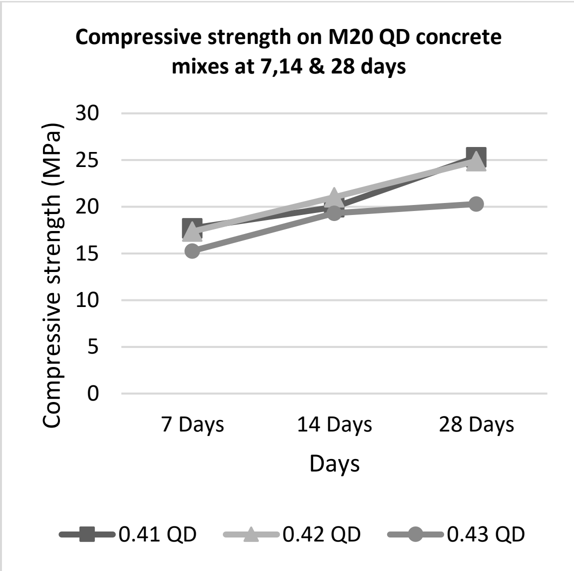

Fig. 3: Compressive strength of M20 QD concrete mixes at 7, 14 & 28 days.

2. Compressive strengths M30 grade QD concrete mixes.

It can be observed that the M30 – 0.41 QD concrete mix showed a reduction in compressive strength at all ages compared to the NS control concrete mixes. M30 - 0.41 QD concrete mix showed 17.62 N/mm^2, 21.68 N/mm^2 & 26.73 N/mm^2 compressive strength value at 7, 14 & 28 days where as control concrete mix showed 18 N/mm^2, 27 N/mm^2 & 32 N/mm^2 strength values.

M30 - 0.42 QD concrete mix showed 14.97 N/mm^2, 17.81 N/mm^2 & 22.95 N/mm^2 compressive strength value at 7, 14 & 28 days where as control concrete mix showed 18 N/mm^2, 27 N/mm^2 & 32 N/mm^2 strength values.

M30 – 0.43 was the concrete mix that had the maximum quarry dust ratio in M30 grade QD mixes. It can be observed that M30 – 0.43 QD concrete mix showed an increment than M30 – 0.42 but lower than M20 – 0.41 QD concrete & NS control concrete mixes. M30 - 0.43 QD concrete mix showed 16.43 N/mm^2, 21.46 N/mm^2 & 25.97 N/mm^2 compressive strength value at 7, 14 & 28 days where as control concrete mix showed 18 N/mm^2, 27 N/mm^2 & 32 N/mm^2 strength values.

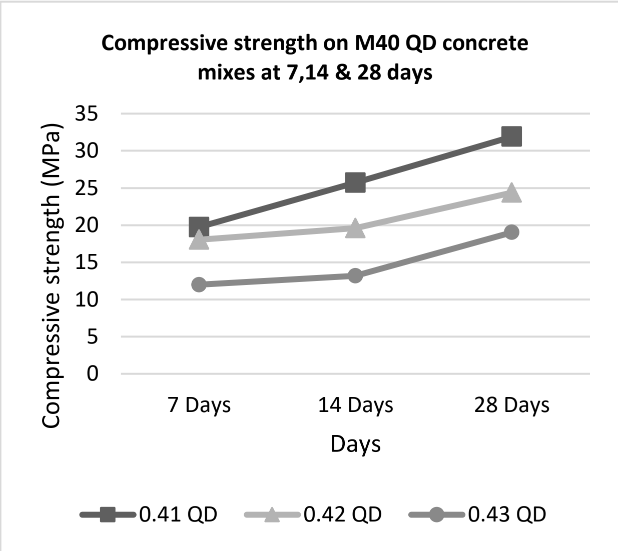

Fig. 4: Compressive strength of M30 QD concrete mixes at 7,14 & 28 days.

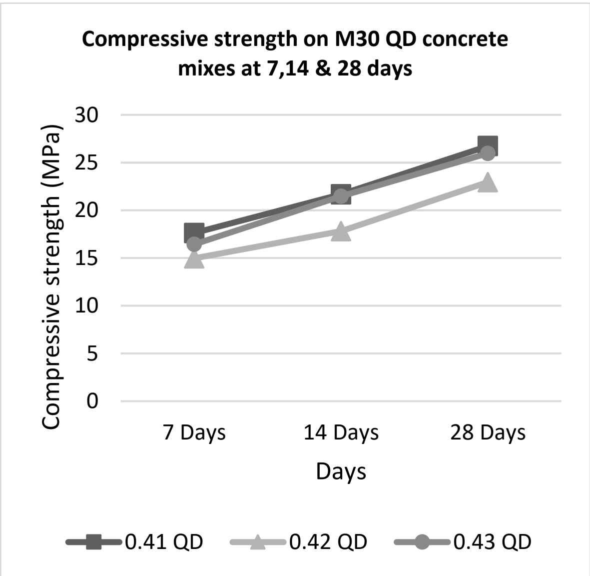

Fig. 5: Compressive strength of M40 QD concrete mixes

3. Compressive strengths M40 grade QD concrete mixes.

M40 – 0.41 QD concrete mix showed a reduction in compressive strength at the all-ages compared to the NS control concrete mixes as shown in fig. 5.

M40 - 0.41 QD concrete mix showed 19.74 N/mm^2, 25.69 N/mm^2 & 31.89 N/mm^2 compressive strength value at 7, 14 & 28 days where as control concrete mix showed 26 N/mm^2, 36 N/mm^2 & 46 N/mm^2 strength values.

It can be seen that the compressive strength values of M40 – 0.42 QD concrete were lower than M40 – 0.41 QD concrete mix with the increment of quarry dust ratio. M40 - 0.42 QD concrete mix showed 18.04 N/mm^2, 19.59 N/mm^2 & 24.37 N/mm^2 compressive strength value at 7, 14 & 28 days where as control concrete mix showed 26 N/mm^2, 36 N/mm^2 & 46 N/mm^2 strength values.

M40 – 0.43 QD mix was the concrete mix that had the maximum quarry dust ratio in M40 grade QD mixes. It can be observed that the M40 – 0.43 QD concrete mix showed the lowest compressive strength values compared to the other two M40 grade QD concrete mixes. M40 - 0.41 QD concrete mix showed 11.99 N/mm^2, 13.2 N/mm^2 & 19.02 N/mm^2 compressive strength value at 7, 14 & 28 days where as control concrete mix showed 26 N/mm^2, 36 N/mm^2 & 46 N/mm^2 strength values.

Overall, the results indicate that the M20 QD mixes have shown the highest compressive strength values among the quarry dust mixes. The reason can be explained by the higher rate of increment of compressive strength on M20 QD

Concrete mixes as the accelerated cement hydration due to the micro fines of quarry dust. Quarry dust accelerates the formation of cement hydration at early stages. For the higher

Increment of compressive strength on M20 QD concrete mixes, the filling effect of micro fines in quarry dust was mainly caused. Because micro fines of quarry dust filled the voids of the concrete mix than natural sand & it enhanced the density in microstructure concrete. Moreover, the specific gravity & intrinsic strength of quarry dust is higher than natural sand particles which might increase the compressive strength of the concrete mixes. The rough surface texture of the quarry dust particles also supported to bond better between aggregates and the cement paste & increased the compressive strength of M20 mixes.

M30 – 0.42 QD mix showed the lowest compressive strength value compared to other M30 QD concrete mixes. Usage of Insufficient & unsuitable cement amount when mixing the concrete or improper compaction due to the human errors and poor interlocking between cement paste & aggregates particles could be caused to the reduction of compressive strength on M30 – 0.42 QD mix.

M40 QD mixes have shown lowest compressive strength values compared to the other QD mixes. Due to a large number of micro fines, cement paste became not enough to bond aggregates particles in the concrete mix properly. So, when the quarry dust ratio was increased compressive strength of the M30, 40 QD mixes slightly decreased.

D. Cost analysis of QD concrete mixes:

The significance of this dissertation study was to optimize the cement quarry dust ratio & cost-effectiveness in construction. Quantity of cement, quarry dust & coarse aggregates were calculated for 1m^3 volume of each QD concrete mix by multiplying the weight with the per-unit price of the material. The total cost of the M20 – 0.41 QD concrete mix is LKR 11382.63 & when compared to the M20 grade 20mm aggregate concrete mix, it is LKR 4218.93 cost reduction. Following this cost calculation method cost for other quarry dust mixes also were calculated. According to the above results, it can be seen that when cement percentage was decreased the percentage of reduction increased. The lower price of quarry dust materials compared to the natural sand & cement reduction was influenced by the increment of cost reduction in quarry dust concrete mixes.

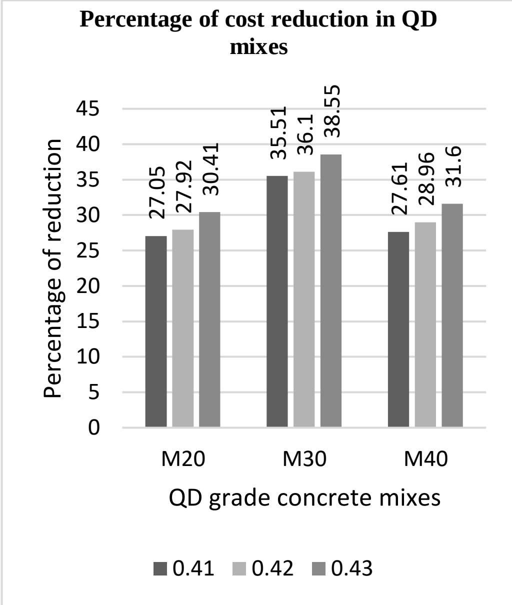

Fig. 6: Percentage of cost reduction in QD mixes

Conclusion

The difference of the particle size distribution between natural sand quarry dust is shown in Fig. 4.1, excessive content of micro fines & angular rough surface texture of quarry dust particles which tends to decrease the workability of quarry dust concrete mix due to the increment of friction between cement paste and aggregates were the major facts to decrease the workability of QD concrete mixes compared to NS concrete mixes.
According to the results from workability, it can be concluded that M20 QD concrete mixes are suitable for structural uses according to Indian standards.
If any admixtures are used for the M30, 40 QD concrete mixes to enhance the workability as mentioned in the past research work of R.Illangnova *et al*., (2008), compressive strength also can be increased.

According to the results compressive strength values of M20 concrete mixes were higher than NS concrete mixes. These mixes can be used as a replacement for natural sand concrete for industrial purposes. Although the compressive strength of M20 – 0.41 QD slightly exceeded the 20 MPa margin level, this mix cannot use for industrial purposes with this water-cement ratio should be changed to increase the workability of the mix.

Then it will be mainly influenced by the higher increment of compressive strength.

According to the results, cost of M30 & M40 QD concrete mixes were lower than NS concrete mixes. The main fact for the reduction of compressive strength value was the lower workability & these mixes have shown better compressive strength values without any admixtures which used enhanced the workability of concrete mixes. It is recommended to use superplasticizer admixture to enhance the workability of the mixes & with proper compaction and better interlocking between cement paste and aggregates which will increase the compressive strength of the QD concrete mix series to use as a replacement of NS concrete mixes for industrial purposes.

In QD concrete mixes which were optimized for cement quarry dust ratios, the percentage of cost reduction stand between 27% to 31% mixes & these mixes are cost-effective compared to conventional concrete mixes.

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