Experimental Study on Compressive Strength of M20 Grade Concrete with Partial Replacement of Cement by Metakaolin and Quarry Dust Powder

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Abstract— Ordinary Portland cement (OPC) is conventionally used as the primary binder to produce concrete. In the world, Cement consumption has increased exponentially since 1926 and is continuing to increase because of its scale of consumption and manufacturing. Cement production in 2003 was approximately1.2 billion tonnes and this was expected to grow to about 4.42 billion tonnes/year by 2021. This reflects global developments and population growth in infrastructure and the excellent strength and durability properties that concrete provides. In the present study Metakaolin and Quarry dust powder used as a partial replacement of cement. In this study, two Mix's was carried out first(Mix-1) is a partial replacement of cement by Metakaolin as 0%, 5%, 10%, 15%, 20%. And second (Mix-2) is Quarry dust powder as the partial replacement of cement by varying percentage of 0%, 5%, 10%, 15%, 20%. For analyzing the suitability of these wastes like Quarry dust powder and Metakaolin in the concrete of M20 grade mix. The compressive strength test for 7 days and 28 days cube has been conducted for all mixes. In this research, the effect of partial replacement of cement by Metakaolin and Quarry dust powder in the design concrete mix has been studied. Based on experimental studies cube specimens have been designed. The optimum percentage of cement replacing with Metakaolin and Quarry dust powder was determined to be 20% for compressive strength. The tests were conducted to study the compressive strength of concrete after finalizing the optimum mix. On comparing the results, it has been found that compressive strength increases on varying percentage replacement of cement by metakaolin and compressive strength decrease on varying percentage replacement of cement by Quarry dust powder.

Keywords: Compressive strength, Metakaolin, Quarry dust powder

I. Introduction

A. General

Conventionally concrete is a proper mixture of cement, sand and aggregate. Concrete is the most widely used building material, with more than 10 billion tonnes produced annually by the construction industry worldwide, hence there is need to look into its sustainability, which finds wider application in the construction industry. Cement both in mortar and concrete is the most important element of the infrastructure and can be a durable construction material. Generally in the design of concrete mix, cement, fine aggregates and coarse aggregates are being used from a long back, which plays a crucial role in designing of a particular grade of concrete. But nowadays there is a scarcity in aggregates. So, some new materials which are locally available for low cost have to be introduced for replacing the fine aggregates, coarse aggregates as well as cement to get the same strength. The mortar and concrete development, with special admixtures or with additions such as pozzolanic materials, allows the improvement of the product quality towards specific requirements of modern construction. In this context, further research is needed for mortar and concrete development or optimization. Some researchers are working on solid waste as partial replacing substances based on the locally available industrial wastes such as Fly ash, Sugarcane bagasse ash, Blast furnace slag, rice husk ash, Wheat straw ash, Silica fumes, Metakaolin, Quarry dust material, glass powder, over burnt bricks, coconut shells etc. All the materials are being used as supplementary cement and fine aggregate additive and replacement materials.

B. Metakaolin (MK)-

In the long term, to extend the practice of partially replacing cement in concrete and mortar with waste and other less energy-intensive process material, which have pozzolanic properties. One possible source for a pozzolanic is calcined clay.

The utilization of calcined clay in the form of metakaolin (MK) as a pozzolanic addition for mortar and concrete has received considerable interest in recent years. Much of this interest has focused on the removal of the calcium hydroxide (CH), which is produced by the hydration of cement and which is associated with poor durability. CH removal has a major influence on-resistance of sulphate attack and alkali-silica reaction (ASR); and also provides enhanced strength, which is derived from the additional cementitious phases generated by the reaction of CH with MK. MK is produced from high purity Kaolin clay by calcinations at moderate temperature (650- 800oC). It contains silica and alumina in an active form which will react with the CH. SCMs used in the manufactured concrete products industry as well as a review of blended cement. There are various types of supplementary cementitious material like fly ash, silica fume, slag cement, Metakaolin, rice husk ash, coconut shell etc. Out of above Supplementary Cementitious Materials (SCMs), we use Metakaolin as partial replacement of cement and experimental investigation is carried out.

C. Quarry Dust Powder

The Quarry dust is one of the mineral admixtures used as a partial replacement of cement and aggregates. It is available in different sizes and shapes. The Quarry dust is durable, hard and highly resistant to biological, chemical and physical degradation forces. Due to the pozzolanic property of Quarry dust the durability is increased. Indian Quarry dust production is more than 100 Million tonnes per year. In

Quarry industry, about 30%- 40% waste material generated from the total production. The Quarry dust is durable, hard and highly resistant to biological, chemical, and physical degradation forces. Quarry dust has been used for different activities in the construction industry, such as building materials, road development materials, aggregates, bricks, and tiles. The use of the replacement materials offers cost reduction, energy savings, arguably superior products, and fewer hazardous in the environment.

II. OBJECTIVE

This project is intended to develop concrete mixes incorporating some materials as replacement of cement. The objective of the study is summarized below:-

To study the compressive strength of concrete by replacement in varying percentage of metakaolin and quarry dust powder by weight of cement.

III. SCOPE OF THE WORK

The scope of this thesis is to study the parameters which influence the compressive strength of the concrete mix M20 grade by replacing cement with Quarry dust material and Metakaolin.

Scope of our present work is cost reduction and at the same time reduction of waste disposal of Quarry dusts. By using Metakaolin the compressive strength increases, when compared with a conventional mix. It also reduces pollution which is caused due to cement production.

IV. MATERIALS USED

A. *Cement*

Cement is the major ingredient in assembling of concrete. . OPC available in the local market of the standard brand was used in the investigation. The Bureau of Indian Standards (BIS) has classified OPC in three different grades. The grades are (i) 33grade (ii) 43grade (iii) 53grade. In this project, 43 Grade Ordinary Portland Cement was used conforming IS, IS 8112-1989. available in local market is used in this entire investigation. It was fresh and free from any lumps and the specific gravity of cement was 3.15.

B. *Fine Aggregate:*

The fine aggregates used in this investigation was Narmada River sand passing through 4.75 mm sieve with specific gravity of 2.65. Fine aggregate is added to concrete to assist workability and to bring uniformity in the mixture. The grading zone of fine aggregates was a zone II as per Indian standard specification. (IScode 383:1970).

S.NO.	Particulars	Value of sand
1	Source	Jabalpur
2	Zone	II
3	Specific gravity	2.65

Table 1: Properties of Fine Aggregate

C. *Coarse Aggregate:*

Machine crushed broken stone angular in shape was used as coarse aggregates. The aggregate which passes through 75 mm sieve and retains on 4.75 mm are known as coarse aggregate. Angular shape aggregate of size is 20 mm and below. It should be hard, strong, dense, durable, clean, and free from clay or loamy admixtures or quarry refuse or vegetable matter. The pieces of aggregate should be cubical, or rounded shaped and should have granular or crystalline or smooth (but not glossy) non-powdery surfaces. Aggregate should be properly screened and if necessary washed clean before use. Coarse aggregate containing flat, elongated or flaky pieces or mica should be rejected. The grading of coarse aggregate should be as per specifications of IS 383-1970. Two fractions of coarse aggregates were used, 20mm size having a specific gravity of 2.68, and 10mm size having a specific gravity of 2.68.

S. No.	Particulars	Value of sand
1	Source	Jabalpur
2	Specific gravity (10 mm)	2.68
3	Specific gravity (20 mm)	2.68

Table 2: Properties of Coarse Aggregate

D. *Water*

Ordinary tape water clean, potable free from suspended particles and chemical substances was used for both mixing and curing of concrete. The water should be fit for mixing. The water should not have high concentrations of sodium and potassium and there is a danger of alkali-aggregate reaction. Natural waters that are slightly acidic are harmless, but water containing organic acids may adversely affect the hardening of concrete. The water should conform to IS 456-2000 standards.

E. *Metakaolin:*

In the present investigation work, the metakaolin used is obtained from Gujarat India. Specific gravity being 2.5. Metakaolin is one of recently developed mineral admixture used to replace apart of cement in the manufacture of cement of HPC. Metakaolin is a manufactured pozzolanic material. It is unique is not a by-product of an industrial process nor entirely natural. It is derived from naturally occurring mineral and manufactured specifically for cementing application. The resulting material has high pozzolanicity and may be used in concrete.

Physical properties		
S. No.	Property	Metakaolin
1.	Colour	White
2.	Physical form	Powder
3.	Specific gravity	2.5
4.	Fineness cm2/gm	150000-180000
Chemical composition		
1.	Calcium oxide (Cao)	0.2-0.9
2.	Silicon dioxide (Sio2)	60-65
3.	Aluminium oxide (Al203)	30-34
4.	Iron oxide (Fe203)	1.00
5.	Magnesium oxide (Mgo)	0.2-0.8
6.	(So3)	-
7.	Potassium oxide (K20)	0.5-1.2
8.	Loss on ignition %	0.98

Table3. The physical & chemical properties of Metakaolin. (With the reference of Kaomin industries INDIA Pvt.Ltd)

F. Quarry Dust Powder (QDP):

The Quarry Dust was taken from the Stone crusher site from Amjhar, Jabalpur district, Madhya Pradesh state, India. Quarry Dust is collected from its disposal site on the Quarry site. It was initially in a dry condition when collected and was sieved by IS: 90-micron sieve before mixing in concrete. Usually, quarry dust is used as a surface filler material in highway constructions. As there is no particular code specified for testing this material, it is checked as per the specifications to fine aggregate in concrete, IS:- 2386 (Part III, reaffirmed 2016).

Chemical properties		
S. No.	compositions	Quarry Dust
1.	Calcium oxide (Cao)	4.83
2.	Silicon dioxide (Sio2)	62.58
3.	Aluminium oxide (Al203)	18.60
4.	Iron oxide (Fe203)	6.56
5.	Magnesium oxide (Mgo)	2.46
6.	Potassium oxide (K20)	3.28
7.	Loss of ignition	0.48
Physical properties		
S. No.	Property	Quarry Dust
1.	Specific Gravity	2.53 - 2.68
2.	Bulk Density(kg/m3)	1710 -1810
3.	Absorption (%)	1.20 - 1.50
4.	Moisture content (%)	Nil
5.	Fine particles less than 0.075mm (%)	12 - 15
6.	Sieve Analysis	ZONE - II

Table 4: The physical & chemical properties of Quarry Dust powder.
Chemical properties As per IS 4032-1968:-

V. MIX DESIGN

Mix Design is done as per Indian standards. The concrete mix has been designed as per procedure mentioned in IS 10262:2009. For determining the proportion of ingredient to achieving the desired grade of concrete, cube specimens were cast and tested after 7 days and 28 days of curing for producing concrete of minimum properties like strength and consistency etc., as economically as possible. Mix design is done for M20 grade concrete.

Cement Kg	Fine aggregate Kg	Coarse aggregate Kg	W/C ratio
383.00	727.00	1103.00	191.50
1	1.90	2.88	0.5

Table 5: Mix Proportions by WEIGHT

VI. METHODOLOGY

In this study Metakaolin and Quarry Dust powder are used as the partial replacement of cement in concrete mixes. No. of mixes of concrete incorporating various percentages of Metakaolin and Quarry dust powder have been prepared and tested to investigate the strength of concrete.

The standard cast-iron moulds are used for casting. The moulds are cleaned of dust particles and the bolts and nuts are well tightened to avoid the water loss. The moulds are applied with mineral oil on all sides before concrete is poured into the moulds. The moulds are placed on a level platform. The well-mixed concrete is filled into the moulds and kept on the vibration table. Excess concrete was removed with a trowel and the top surface is finished level and smooth as per IS 516-1969.

- For Compressive strength test standard cube size of 150mm x 150mm x150mm are used. An average of three specimens is taken for all mixes.
- 06 numbers of cube specimens have been prepared for M20 grade concrete without using Metakaolin and Quarry dust powder. 06 cube specimens have been tested for compressive strength at the age of 7 days and 28 days.
- 48 numbers of cube specimens have been prepared for M20 grade concrete using MK and QDP. 48 cube specimens have been tested for compressive strength at the age of 7 days and 28 days.

VII. TESTING, RESULTS AND DISCUSSIONS

A. Workability Test

1) Slump Test:

Slump test is used to determine the workability of fresh concrete. Slump test as per IS 1199: 1959 is followed. The apparatus used for doing a slump test was slump cone and tamping rod. The internal surface of the mould was thoroughly cleaned and freed from superfluous moisture and adherence of any old set concrete before commencing the test. The mould was then filled in four layers, each 1/3 of the height of the mould, each layer being tamped 25times with a standard tamping rod taking care to distribute the strokes evenly over the cross-section. After top layer had been riding, the concrete was struck off level with a trowel and tamping rod. The mould was removed from the concrete immediately by raising it slowly and carefully in a vertical direction. This allowed concrete to subside. This subsidence was referred to a slump of concrete. The difference in level between the height of the mould and that of the highest point of the subsided concrete was measured. This difference in height in mm has been taken the slump of concrete.

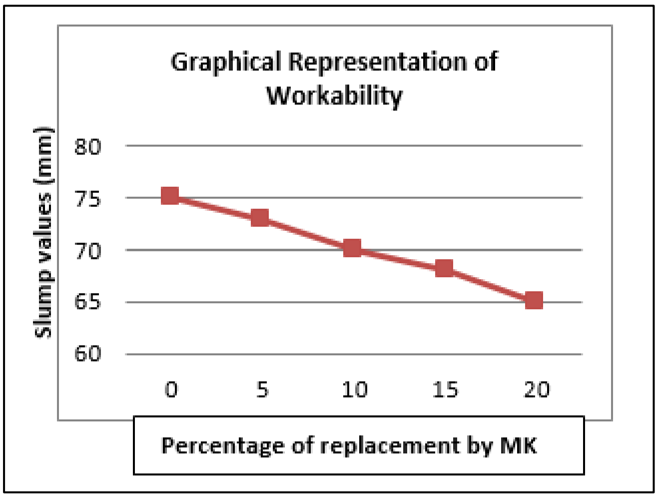
Slump value decreased upon the availability of MK when it replaces OPC 43grade. It can be concluded that to achieve good workability, mixes containing MK will require a higher amount of water than conventional mixes.

The workability decreased from 75 mm to 65 mm if replacement of cement by MK is 0% to 20% shown In Table 6.1. The variation of slump values is represented in a graph in fig 6.1

Slump value increases when Quarry dust powder is included in cement as a replacement of OPC cement-. Workability is increased from 75 to 85 mm when replacement of cement by QDP is 0% to 20% as shown in table 6.2 .the variation of slump values is represented in a graph in fig 6.2

S.no.	%replacement of cement by MK	Workability (slump) mm
1.	0%	75
2.	5%	73
3.	10%	70
4.	15%	68
5.	20%	65

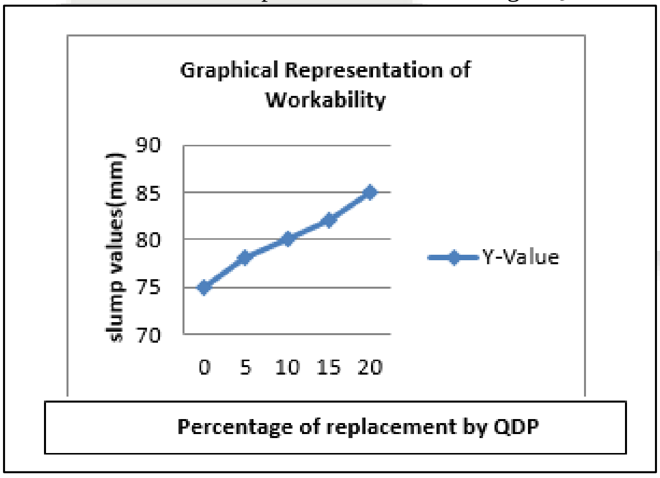
Table 6.1: A Slump of concrete containing MK.



Graph 6.1: Effect of MK on workability of concrete.

S. no.	% replacement of cement by QDP	Workability (slump) mm
1.	0%	75
2.	5%	78
3.	10%	80
4.	15%	82
5.	20%	85

Table 6.2: A Slump of concrete containing DQP.



Graph 6.2: Effect of QDP on workability of concrete.

2) Compressive Strength Test:

For Compressive strength test standard cube size of 150mm x 150mm x150mm are used. An average of three specimens is taken for all mixes. A compressive testing machine of 2000 KN capacity with a least count of 10 KN was used for testing the compressive strength of the specimens the specimens are water cured for 28 days. The specimen was placed on the platform of the compression testing machine. The load was applied gradually until the failure stage. The specimens were tested after a curing period of 28 days. The ultimate load was noted and calculated the compressive strength of the corresponding specimen.

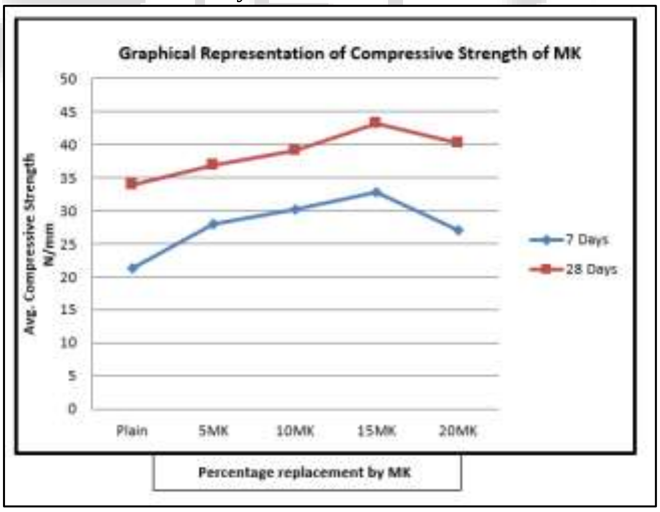
Compressive strength is obtained by applying a crushing load on the cube surface. So it is also called as Crushing strength. Compressive strength is regarded as the paramount property of any concrete mix. Cubes are cast with cement replaced with varying percentages of metakaolin and quarry dust powder to test the compressive strength. The test results are presented here for the compressive strength of 7 days, 28 days.

No. of days	Cube1 strength (N/mm^2)	Cube2 strength (N/mm^2)	Cube3 strength (N/mm^2)	Average compressive strength (N/mm^2)
7 days	21.78	21.34	20.89	21.33
28 days	34.23	33.34	34.00	33.84

Table 7. Strength of cube for 7days and 28 days. (For Nominal Mix)(M20)

Designation Mix-1 (%Replacement of cement by MK)	Compressive strength N/mm^2		Average compressive strength N/mm^2	
	7 days	28 days	7 days	28 days
MK 5%	28.00	36.44	27.99	36.81
	27.55	37.11		
	28.44	36.89		
MK 10%	30.66	39.11	30.21	39.18
	29.77	39.55		
	30.22	38.88		
MK 15%	32.44	42.66	32.88	43.18
	33.33	43.78		
	32.88	43.12		
MK20%	26.67	40.22	27.12	40.23
	27.12	40.00		
	27.56	40.45		

Table 8. Result of compressive strength testing for 7days and 28days for Metakaolin. Mix-1.

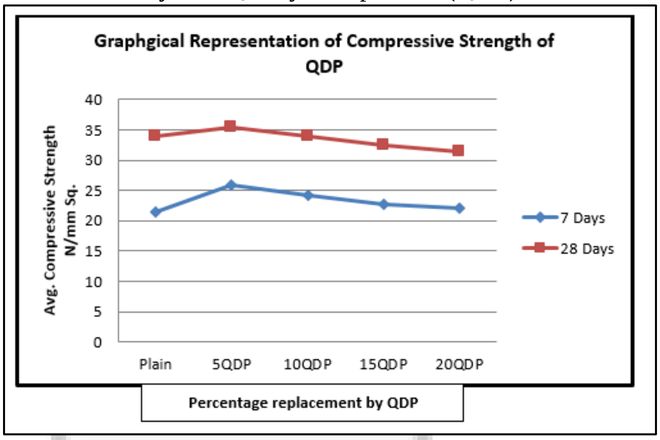


Graph 8.1.: Compressive strength for 7 days and 28 days for nominal mix and partial replacement of cement by metakaolin.

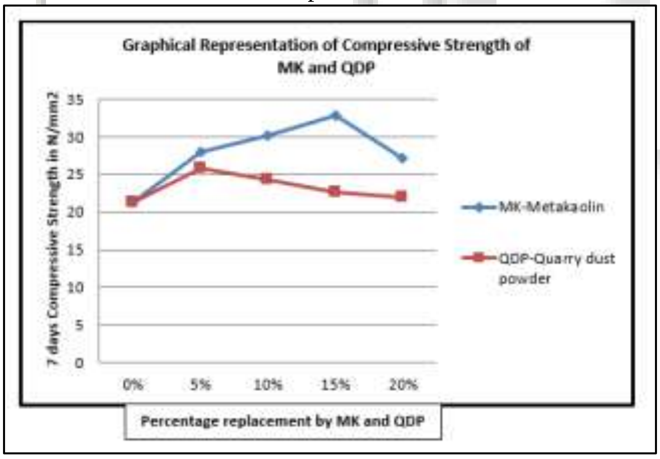
S. No.	Designation Mix-2 (%Replacement of cement by QDP)	Compressive strength N/mm^2		Average compressive strength N/mm^2	
		7 Days	28 days	7 days	28 days
1	QDP 5%	25.78	34.89	25.85	35.37
		25.56	35.88		
		26.23	35.34		

2	QDP 10%	24.44	33.56	24.23	33.86
		24.00	33.78		
		24.23	34.23		
3	QDP 15%	23.12	32.45	22.67	32.48
		22.23	32.89		
		22.67	32.11		
4	QDP 20%	22.89	31.23	22.01	31.37
		21.78	32.00		
		21.34	30.87		

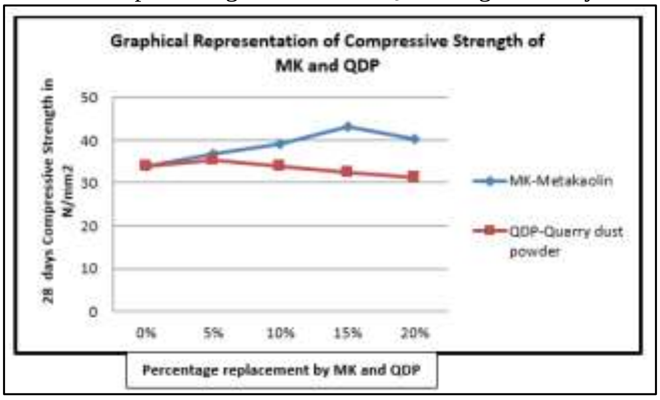
Table 9: Result of Compressive strength testing for 7 and 28 days for Quarry dust powder (QDP)



Graph 9.1: Compressive strength at 7 days and 28 days for nominal mix and partial replacement of cement by Quarry dust powder.



Graph 10: Relationship of compressive strength between different percentage of MK and QDP at age of 7 days.



Graph 11: Relationship of compressive strength between different percentage of MK and QDP at age of 28 days.

VIII. Discussion on Results

Based on the experiments conducted on M-20 grade of concrete and partial replacement of cement with varying percentage of metakaolin and quarry dust powder. The following points are observed.

1) The workability of concrete increases with an increasing percentage of Quarry dust powder.
2) The workability of concrete decreases with an increasing percentage of Metakaolin.
3) On replacement of 5%, 10%, 15% and 20% metakaolin as partial replacement of OPC, the 28 days compressive strength increases by 8.78%, 15.78%, 27.60%, 18.88% of concrete as compared to nominal mix.
4) On replacement of 5%, 10%, 15% and 20% quarry dust powder as partial replacement of OPC, the 28 days compressive strength increase by 4.52%, and decreases by 0.06%, 4.01%, and 07.29% of concrete as compared to nominal mix.
5) The compressive strength of concrete with partial replacement of OPC by 15% metakaolin has been found to be maximum.
6) The increase in 28 days compressive strength at 15% replacement is 27.60%.

IX. Conclusions

Based on the test results obtained from this study the following conclusion can be drawn.

1) The compressive strength test results show that the metakaolin is superior to QDP in terms of the strength enhancement of concrete.
2) Among different replacement levels, the use of metakaolin at the replacement level of 15% performed the best, which resulted in the highest strength increase.
3) The compressive strength at the age of 7 days and 28 days was increased at mix M1 (15%MK) of about 27.60% than the Nominal mix concrete.
4) The strength achieved with the replacement of 5% Quarry dust powder shows highest compressive strength. When increase varying percentage of QDP compressive strength is reduced.
5) From the experimental investigations we found a possible alternative solution of safe disposal of Quarry dust.
6) From the experimental investigation we found a maximum strength by using metakaolin material.

All of the concrete mixes made by incorporating various proportions of MK and QDP. MK satisfies the criteria for Concrete and hence is recommended for use in the construction of different applications.

Concrete made with cement being replaced by quarry dust (up to 5%) is recommended to be used for making lightweight structural concretes.

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