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Comparative study on strength and economy of conventional and high-performance concrete using crushed sand and river sand

Akshay Kamble
adk.jsp@gmail.com
Bhivarabai Sawant College of Engineering and Research,
Narhe, Pune, Maharashtra

ABSTRACT

The concrete which incorporates wastes and is environment-friendly is called as green concrete. Green concrete is a revolutionary concept in the history of the construction industry. Concrete is an eco- friendly material and the overall impact on the environment per ton of concrete is limited. The paper focuses on the aspect of choosing a material for green concrete. It presents the feasibility of using fly ash, quarry dust, marble powder, plastic waste, and recycled concrete and masonry as aggregates in concrete. The use of fly ash and stone quarry dust in concrete contributes to a reduction in bad environmental repercussions. To avoid the pollution and reuse of waste material, the present study is carried out by completely replacing natural sand in concrete by stone quarry dust and undergoing strength and economical perspectives of concrete and especially in high-performance concrete.

Keywords— *Green concrete, Super plast RMP-1, Stone quarry dust, Compression tests, Contingencies, Pozzocrete, High performance concrete*

1. INTRODUCTION

Green concrete is a concept of using environment-friendly materials in concrete, to finally make the system more sustainable. Green concrete is cheap to produce since waste products or recycled materials are used as a partial substitute for cement, charges for the disposal of waste are avoided, energy consumption while production is quite lower, and durability is much greater. This concrete is often confused with its color. Waste can be recycled to produce new products or can be used as admixtures to relieve the burden on precious natural resources and also causing minimal negative impacts on the environment. Inorganic residual or tailing products like stone quarry dust, crushed concrete debris, marble waste can be used as green aggregates in concrete. Further, by replacing cement with fly ash, micro silica in larger amounts, to produce new green cement and binding materials can ultimately lead to the use of alternative raw materials and fuels producing cement with low energy consumption. Considerable research has been carried out on the use of various industrial by-products and micro-fillers in concrete and their impact on concrete characteristics.

The main concern of using pozzolanic wastes was not only the cost effectiveness but also to improve the durability characteristics of concrete. It is a concept of thinking environment into a broader perspective of the raw materials manufacture over construction, mixture design to structural design, and durability. Since normal construction practices are guided by short term economic considerations, sustainable approach in construction mainly focuses on best practices which emphasize on long term affordability, durability and effectiveness in every stage of the life cycle of the construction. It increases ease and quality of life while having minimal negative environmental impacts and increasing the economic sustainability of the construction. Any infrastructure designed and constructed in a sustainable way minimizes the use of natural resources throughout the life cycle of the construction process and green or eco-friendly concrete helps in achieving the said target.

The use of stone quarry dust in concrete helps in minimizing river sand consumption and provide benefits like improved strength and workability of concrete with useful disposal of by-products.

2. OBJECTIVES OF PROJECT

- To use stone quarry dust as a complete replacement of fine aggregate in concrete.
- To conduct experimental analysis for compressive strength of M20 and M25 concrete grades using 100% stone dust for natural sand as fine aggregate.
- To compare the economic feasibility of conventional concrete and green concrete made with stone quarry dust.
- To check the suitability of crushed sand in higher grades of concrete with the incorporation of pozzocrete.
- To conduct durability tests on high-performance concrete.

3. REVIEW OF LITERATURE

There are an increasing trend and incentives for greater use of manufactured and recycled aggregates in construction. In order to aim for sustainable construction, the incorporation of waste products in concrete like fly ash, ground granulated blast furnace slag and silica fume as substitutes for Portland cement being industrial by-products is gaining huge success in the construction industry. To achieve cost-effectiveness and improved properties of concrete, use of pozzolanic wastes gained huge importance. The material for green concrete can be selected based on parameters like resource efficiency, indoor air quality, energy efficiency, water conservation and affordability. Quarry rock dust a non-valuable waste material after processing of rocks can be incorporated in concrete to achieve better sulphate and acid resistance with low permeability. However, the water absorption of Quarry Rock Dust is slightly higher than conventional concrete. [1]

The auspicious attributes of concrete like durability, availability, versatility, good compressive strength; it is one of the most commonly used building materials throughout the world. The demand for infrastructural facilities creates enormous pressure on concrete which makes it unavoidable to search for alternative construction materials. Substituting sand by stone dust will serve waste management as well as can prove to be alternative material in concrete. The value of compressive strength is higher for30% replacement level for different grades of concrete whereas maximum tensile strength occurs at 20% replacement level and the corresponding tensile strength is around 12% higher than normal concrete. [2]

Experimental studies were carried out to judge the potential of using quarry dust as a complete replacement for natural sand. Cement concrete cubes of grades M20 and M25 were studied and tested for strength and workability with various proportions of fine aggregate. A mix ratio of 1:1.5:3 gave the optimum strength in the study. As the percentage of quarry dust increases gradually, compressive strength increases with the condition that the percentage of replacement must not exceed 50%. [3]

The investigation was undergone with a view to verify the suitability, feasibility and potential use of crusher dust as waste material from aggregate crushing plants, in terms of its compressive strength and workability. An attempt was made to replace the natural sand in controlling concrete mixes of M20 and M30 grades designed for 100 to 120mm slump at replacement levels of 30%, 40%, 50% and 60% using Portland pozzolanic cement. From the test results, it was observed that that replacement of natural sand by stone quarry dust increased the compressive strength of concrete by 5-22%.

Amongst all the mixes, maximum compressive strength was obtained for 40% replacement of sand by stone quarry dust. [4]

4. METHODOLOGY

- The project work focuses on the incorporation of stone quarry dust as a complete replacement for sand in concrete.
- It is clearly observed that there is a reliable increase in the strength of plain concrete when natural sand is fully replaced by quarry dust.
- The study gives attention towards physical and chemical properties of quarry dust which are satisfied in respect of requirements of codal provision. The complete replacement of sand with quarry dust gives better results in terms of compressive strength studies.
- Experimental work involved concrete cubes casting of different grades with the incorporation of stone quarry dust and strength properties be studied in detail.
- The obtained strength results were compared with river sand results for strength and economical aspect of concrete.
- The economic aspect of concrete made with 100% river sand and quarry dust was studied by undergoing a case study.
- A further cost feasibility analysis was done in comparison with conventional and green concrete made using stone quarry dust.
- The study of the suitability of crushed sand in high-performance concrete was studied in terms of compressive strength.

5. OBSERVATIONS AND CALCULATIONS

Preliminary tests were conducted on concrete materials as per IS standards and specifications for analyzing the physical and engineering properties, cubes were cast in standard metallic moulds and vibrated to obtain the required sample size of the specimen. The moulds were cleaned initially and oiled on all sides before pouring concrete inside it. Thoroughly mixed concrete was poured into the moulds in three equal layers and compacted using the vibrating table for 5 minutes. The excess concrete was removed out of the mould using a trowel and top surface was finished to smooth surface. After 24 hours the samples were demoulded and put in curing tank for a period of 7, 14 and 28 days with a set of 3 samples prepared for each stage of curing. The temperature of curing tank was maintained at 25 degrees and finally, the compressive strength values were tabulated.

5.1 Materials used

5.1.1 Birla Super OPC 53 Grade conforming to IS 12269 (W=14, M=4, Y=12)

Table 1: Test report of cement

Name of test	Result	Unit	Specified limits
Standard Consistency	28.50	%	-------
Initial Setting time	140	Min.	Min. 30 minutes
Final Setting time	280	Min.	Max.600 Minutes
3 days compressive strength	34.90	N/mm^2	Min. 27 N/mm^2
28 days compressive strength	56.55	N/mm^2	Min. 53 N/mm^2

References

1) IS 269-1989 for OPC 33 Grade
2) IS 455-1989 for Portland Slag Cement
3) IS 1489 (Part 1 & 2) -1991 for PPC (Fly ash based)
4) IS 8112-1989 for OPC 43 Grade

5.1.2 Fine and Coarse Aggregate

Table 2: Fine aggregate (crushed sand) test report

Test	Result	Unit
Condition of sample	Moist	
Moisture Content	1.01	%
Loose Bulk Density	1.75	Kg/lit
Specific Gravity	2.74	
Water Absorption	3.39	%
Material finer than 75 microns	18.80	%

Table 3: Coarse aggregate test report

Test	Result	Unit
Condition of sample	Dry	
Loose Bulk Density	1.51	Kg/lit
Specific Gravity	2.91	
Water Absorption	1.14	%
Flakiness Index	12.3	%

Table 4: Sieve analysis (F.A.)

Sieve Sizes	Wt. Retained (g)	Wt. Retained %	Cumulative Wt. Retained %	Passing %
10 mm	0	0.00	0.00	100.00
4.75mm	0	0.00	0.00	100.00
2.36mm	134	13.44	13.44	86.56
1.18mm	315	31.60	45.04	54.96
600micron	165	16.55	61.59	38.41
300micron	101	10.13	71.72	28.28
150micron	60	6.02	77.74	22.26
75 micron	49	4.92	82.66	17.34
Pan	173	17.35	100.00	0.00
Total	997		Fineness Modulus=	2.695

Table 5: Sieve analysis (C.A.)

Sieve Sizes	Wt. Retained (g)	Wt. Retained %	Cumulative Wt. Retained %	Passing %
40mm	0	0.00	0.00	100.00
25mm	0	0.00	0.00	100.00
20mm	0	0.00	0.00	100.00
16mm	430	21.51	21.51	78.49
12.5mm	1270	63.53	85.04	14.96
10 mm	282	14.11	99.15	0.85
4.75mm	15	0.75	99.90	0.10
Pan	2	0.10	100.00	0.00
Total	1999			

Fig. 1: C rushed sand on site

Fig. 2: Sieve analysis by sieve shaker

6. EXPERIMENTAL WORK

Compression Test and Slump cone tests were conducted to judge the most reliable and realistic characteristics of hardened concrete. The compression test was carried out on the Cubical specimen; the cube of size 150mm x 150mm x 150mm. The 20 mm coarse aggregate (Metal) was used to make concrete mixes. This test will be conducted for concrete cubes of 100%.Replacement of river sand by quarry dust (nowadays rivers and is least used in concreting work) for M20 and M25mixes.

6.1 Final Concrete Mix Design for M20 Grade:

Mix proportions: (all weights in kg)

Table 6: Mix design M20

For	Cement	Fly Ash	Crushed sand	20mm aggregate	Water
One bag	50	11	150	220	33.55
Per m3	270	60	811	1190	181.50

Water binder ratio: 0.55
Total cementitious material = 330kg/m^3
Cement used= Vasavadatta OPC 53 Grade IS 12269 (W=01, M=01, Y=14)
Slump achieved: 80 mm

Target mean strength=f_{ck} N/mm^2 + (K × Standard Deviation)

Assumed Standard Deviation= 4N/mm^2 (As per IS 456-2000 Table 8, Clause 9.2.4.2)

Target mean strength = 20.00 + (1.65 × 4) = 26.6 N/mm^2
Plastic density = 2513 kg/m^3
Average 7 days compressive strength = 14.22 N/mm^2
Average 28 days compressive strength = 29.27 N/mm^2

6.2 Final Concrete Mix Design for M25 Grade

Table 7: Mix design M25

For	Cement	Fly Ash	Crushed sand	20mm aggregate	Water
One bag	50	10	133	204	30.00
Per m^3	295	60	788	1204	177.50

Water binder ratio: 0.50
Total cementitious material=355 kg/m^3
Cement used=Vasavadatta OPC 53 Grade IS 12269 (W=01, M=01, Y=14)
Slump achieved: 80 mm

Target mean strength=f_{ck} N/mm^2 + (K × Standard Deviation)

Assumed Standard Deviation= 4N/mm^2 (As per IS 456-2000 Table 8, Clause 9.2.4.2)

Target mean strength = 25.00 + (1.65× 4) = 31.6 N/mm^2
Plastic density = 2524 kg/m^3
Average 7 days compressive strength = 18.81 N/mm^2
Average 28 days compressive strength = 33.75 N/mm^2

Thus the target compressive strength can be achieved by complete replacement of river sand by stone quarry dust in concrete and enhanced workability be maintained by mixing suitable admixtures like fly ash and certain chemicals in concrete.

Fig. 3: Pictures of the project

Fig. 4: Casting of moulds

7. ECONOMICAL ASPECT OF CRUSH SAND VS RIVER SAND

Sand is one of the important ingredients in construction works. A huge amount of concrete is consumed in everyday construction works. About 35% volume of concrete comprises of sand as fine aggregate. Generally, cement and coarse aggregates are industrial products whose quality and standards can be easily controlled and maintained. The sand is usually extracted from river beds or river bank by digging. The natural sand deposits are getting exhausted by continuous digging causing damage to the environment in multiple ways. As the availability of suitable natural sand near the point of consumption is becoming exhausted, the concrete production faces a big challenge regarding timely supply. The construction industry needs to tackle the above problem by searching for alternatives. This is also resulting in poor qualities of sand, particularly containing silt. The challenge can be solved by using stone dust in construction works. It is a better substitute for natural sand to cope up with the increasing demand for sand in the construction industry. Hence, here we will study a brief comparison of these materials to help you make the correct viable choice.

The cost of crushed sand will depend on the distance between the site and quarry source. But ultimately the increased availability of crusher plants can reduce the cost and will make it cheaper than river sand. In order to study the economic aspect of crush sand as a viable alternative, a case study was undertaken to investigate the cost-saving aspect of M –sand.

In order to study the economic aspect of crush sand as a viable alternative, a case study was undertaken to investigate the cost-saving aspect of M –sand.

Fig. 5: Site Suyash Nisarg Project area- 3 acres

Fig. 6: Pictures of concreting on site

7.1 Mix design

Referring to the mix design proportions of IS 10262:2009 for M20 grade concrete:

Table 8: Cost of M20 grade per m^3

Material	Weight (kg)	Volume=Mass/ Density (in m^3)	Volume in (ft^3)	Rate per ft^3	Cost
Cement	50	0.035	1.24	260/-	260/-
Crush sand	150	0.103	3.63	30/-	108.90/-
Labour charges (including contingencies+ T&P+ Water charges)					70/-
Total cost					563.40/-
Final cost/m^3=Total cost x 6.4 bags cement					**3606/-**

Table 9: Cost of M20 grade per m^3

Material	Weight (kg)	Volume=Mass/ Density (in m^3)	Volume in (ft^3)	Rate per ft^3	Cost
Cement	320	0.224	7.91	260/- (1.24 Cft)	1659/-
River sand	833	0.52	18.366	70/-	1285/-
Aggregate (20mm)					1120
Labour charges (including contingencies+ T&P+ Water charges)					70/- x 6.4 = 448/-
Total cost /m^3					**4028/-**

Table 10: Cost of M25 grade per m^3

Material	Weight (kg)	Volume=Mass/ Density (in m^3)	Volume in (ft^3)	Rate per ft^3	Cost
Cement	50	0.035	1.24	260/-	260/-
Crush sand	133	0.091	3.24	30/-	97.2/-
Aggregate (20mm)					204
Labour charges (including contingencies+ T&P+ Water charges)					70/-
Total cost					3478/-
Final cost/m^3=Total cost x 6.4 bags cement					**3478/-**

Table 11: Cost of M25 grade per m^3

Material	Weight (kg)	Volume=Mass/ Density (in m^3)	Volume in (ft^3)	Rate per ft^3	Cost
Cement	320	0.224	7.91	260/-	1659/-
River sand	707	0.442	15.61	70/-	1093/-
Aggregate (20mm)	1085	0.70	24.72	25/-	618/-
Labour charges (including contingencies+ T&P+ Water charges)					70/- x 6.4 = 448/-
Total cost /m^3					**3818/-**

The cost per cu.m. for M20 and M25 grades of concrete by considering 100% crushed sand and 100% river sand as fine aggregate is calculated by following the mix design procedures for calculating the number of materials and the current rates on site of the required materials is considered. Following data were considered for analysis:

(a) IS 10262:2009
(b) The density of cement: 1428.57 Kg/m3
(c) The density of crushed / stone quarry dust: 1450 Kg/m3
(d) The density of metal/coarse aggregate: 1550 Kg/m3
(e) Cement (1 Bag) : 260/-
(f) Crushed sand: 30/- per ft3
(g) River sand: 70/- per ft3
(h) Metal/Coarse aggregate: 25/- per ft3
(i) 6.4 Bags of cement considered for per m3 of concrete.
(j) Labour charges including contingencies, T& P and water charges, miscellaneous charges: 70/- per ft3.

After a thorough analysis of all the factors and mix design criteria, the overall cost per cubic meter of concrete is estimated and mentioned in tabulated format.

Further, this data generated was implemented in a case study of Suyash Nisarg site near Hadapsar, Pune, Maharashtra for studying the economic feasibility of concrete using stone quarry dust. The commercial building of the project was selected for the said purpose.

The concreting work details for commercial building (4 floored) are tabulated as below:

Table 12: Cost of concreting details

S no.	Structural Member	Particulars	Concrete grade	Volume (m^3)	Cost (Crush Sand)
1	Footing (substructure)	Footing (P.C.C.)	M20	19.59	70641.54/-
		Footing	M20	68.28	246217.68/-
		Raft Footing (P.C.C.)	M20	28.34	102194.04/-
		Raft Foundation	M25	276.71	962397.38/-
2	Column	Plinth to Raft slab	M25	5.51	19163.78/-
3	First slab	Slab	M25	61.11	212540.58/-
3	Second Slab	Mezzanine slab	M25	10.27	35719.06/-
		Slab	M25	81.63	283909.14/-
		Column	M25	20.42	71020.76/-
4	Third Slab	Slab	M25	81.63	283909.14/-
		Column	M25	16.41	57073.98/-
5	Fourth slab	Slab	M25	83.50	290413/-
		Column	M25	16.41	57073.98/-
				Total cost	**26,92,274/-**

Table 13: Cost of concreting details

S no.	Structural Member	Particulars	Concrete grade	Volume (m^3)	Cost (River Sand)
1	Footing (substructure)	Footing (P.C.C.)	M20	19.59	78908.52/-
		Footing	M20	68.28	275031.84/-
		Raft Footing (P.C.C.)	M20	28.34	114153.52/-
		Raft Foundation	M25	276.71	1056478.78/-
2	Column	Plinth to Raft slab	M25	5.51	21037.18/-
3	First slab	Slab	M25	61.11	233317.98/-
3	Second Slab	Mezzanine slab	M25	10.27	39210.86/-
		Slab	M25	81.63	311663.34/-
		Column	M25	20.42	77963.56/-
4	Third Slab	Slab	M25	81.63	311663.34/-
		Column	M25	16.41	62653.38/-
5	Fourth slab	Slab	M25	83.50	318803/-
		Column	M25	16.41	62653.38/-
				Total cost	2963539/-

% saving in cost by using crushed sand as a substitute for river sand = 9.153%

8. HIGH PERFORMANCE CONCRETE USING POZZOCRETE& M SAND

Pozzocrete Fly ash is an artificial pozzolan, specially designed to achieve optimum performance on most cement and concrete applications. The product confirms IS 3812, EN 450 (S Category) and American standard ASTM 618. In the production of pozzocrete 40™, 60™,80™ high-quality PFA were selected and industrially processed in order to obtain maximum performance as a cement replacement product.

Design of pozzocretes grades has taken into account severe weather conditions, high cement replacement volume, adequate strength development, avoiding short term damage and plastic shrinkage.

For OPC, cement replacement rates of pozzocrete are up to 35% in concrete and P10 (Pozzoplast) can replace 33% of binder content in mortar and 20% of sand replacement which significantly improves batch size by 1.5 times leading to economical mix designs.

Nowadays conventional concrete is posing a lot of problems in terms of durability, time of construction, retrofitting works and larger sections.

So an effort to check the feasibility and suitability of crushed sand in high-performance concrete was undertaken by conducting laboratory tests on compressive strength of cube samples 3 each for different stages of curing incorporating pozzocrete in combination with crush sand in concrete.

9. DESIGN PHILOSOPHY OF HIGH-PERFORMANCE CONCRETE

(a) Performance requirement at fresh as well as solid state
(b) Selection of materials.
(c) PC based admixtures.
(d) Numerous lab trials are performed with experienced personnel.
(e) Standard specifications regarding cement content or w/c ratio are to be taken into consideration.
(f) The requirement of high early strength.

Taking into consideration high early strength and durability requirements, the following ingredients are must in concrete:
(a) OPC 53 with 3 days strength at least 35 MPa.
(b) Classified processed fly ash confirming to IS-3812 (Part I)
(c) PC based admixtures (third generation) with higher PC concentration.
(d) Good quality aggregates confirming to IS-383-1970.
(e) Viscosity modifying agents if self-compacting concrete is required.
(f) Ultra-fine materials.
- Design strength: 40 MPa (3 days) 80 MPa (28 days)
- Durability requirements: RCPT Value<1000 and water penetration value< 15 mm.

Following mix design procedure we arrive at the following data:

S. no.	Materials	Quantity (Kg)
1.	OPC-53	360
2.	Pozzocrete 60 (FA)	100
3.	P100	40
4.	Crush sand	1007
5.	20 mm metal	604
6.	10 metal	403
7.	Water	135
8.	PC based admixture	4

Compressive strength achieved by high performance concrete:
3 days: 43.83 MPa
28 days: 84.61 MPa

10. RESULTS

The results are shown in figure 7 and figure 8, where Graph in figure 7 are indicating comparison of compressive strength (MPa) of M20 Grade concrete using 100% River sand and M sand and Graph in figure 8 is indicating comparison of compressive strength (Mpa) of M25 Grade concrete using 100% River sand and M sand.

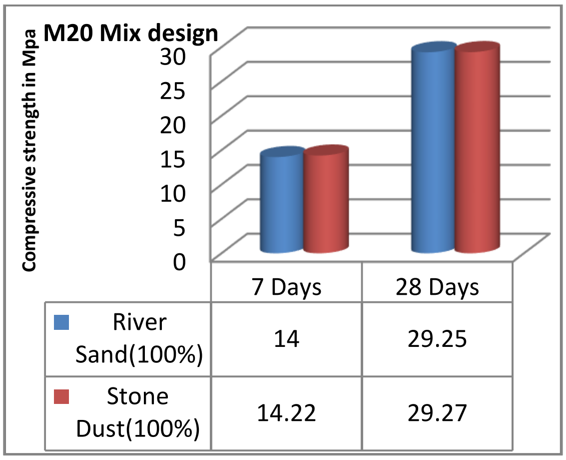

Fig. 7: compressive strength (MPa) of M20 Grade concrete

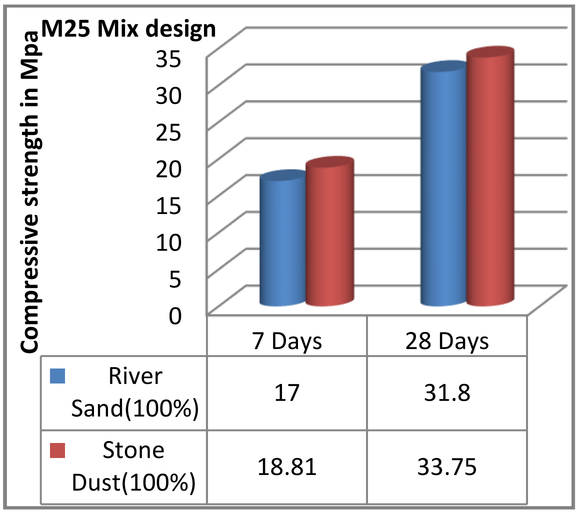

Fig. 8: compressive strength (MPa) of M25 Grade concrete

After a detailed analysis of case study regarding the economical feasibility of concrete carried out on site, the following results were obtained:

Concreting overall cost:

(a) On 100% usage of river sand as fine aggregate in concrete= INR **26, 92,274/-**

(b) On 100% usage of river sand as fine aggregate in concrete = INR **29, 63,539/-**

Thus the saving of INR 2, 71,265 is achieved by incorporating stone quarry dust as a complete replacement for river sand in concrete which comes about 10% of saving which can prove immensely helpful for commercial projects leading to a huge saving in cost.

High performance concrete with design strength of 80 MPa gave excellent results in terms of compressive strength. Crushed sand can be well suitably be used in higher grades of concrete with pozzolans or admixtures with enhanced workability and earlier strength.

11. CONCLUSION

The result of this study has great significance for providing even more high strength as well as durable concrete by using stone dust. This paper presents the compressive strength of M20 and M25 grades of concrete after 7 and 28 days of curing and also the economic feasibility of concrete using crushed sand. On the basis of experimental results following conclusions can be drawn:

- The compressive strength of M20 grade concrete using stone dust as a complete replacement for river sand is 29.27 MPa which is near about same as 29.25 MPa obtained by using river sand.
- The compressive strength of M25 grade concrete using stone dust as a complete replacement for river sand is 33.75 MPa which is higher than 31.80 MPa obtained by using river sand.
- After a lot of research work done in past regarding replacement of natural sand by stone dust in concrete, it can be concluded that river sand can completely be replaced by crushed sand with the incorporation of flyash and plasticizers for achieving workability and strength results.
- Stone dust can prove economical in case of mega projects because of the rising cost of river sand and its unavailability.
- Use of stone dust in higher grades of concrete can be well accomplished in terms of compressive strength achievements.
- Further research will undergo durability tests like RCPT and water permeability on concrete made with crushed sand.

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