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Weathered Crystalline Rock: Suitability As Fine Aggregate In Concrete – A Comparative Study

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Abstract: Concrete is one of the most versatile building materials used in the world. It is prepared by mixing cement, fine aggregate, coarse aggregate and water in suitable proportions. From earlier days onwards river sand is used as fine aggregate. Nowadays, M-sand, pit sand etc. are also used. Since pit sand is available only at certain regions and due to the scarcity of river sand and M-sand, it has become necessary to find an alternative material, as fine aggregate. The alternative material selected here is sand from Weathered Crystalline Rock. And this type of rock is abundantly available at low cost in tropical areas. This paper discusses the use of Weathered Crystalline Sand as fine aggregate in concrete. A comparison of properties like fineness, specific gravity, bulking of sand, bulk density, compressive strength of mortar cubes and compressive strength of concrete cubes using different fine aggregates is also conducted.

Keywords: Fine aggregate, weathered crystalline rock, river sand replacement, scarcity of river sand, manufactured sand

I. INTRODUCTION

A. General

Concrete is widely used in domestic, commercial, recreational, rural and educational construction. Communities around the world depend on concrete as a safe, strong and simple building material. It is used in all types of constructions. Despite the common usage of concrete, a few people are aware of the considerations involved in designing strong, durable, high quality concrete.

Construction industry has undergone a rapid change in the last century especially with the advancement of different types of concrete. Concrete is the largest produced construction material. The production of concrete is of the order of 10 billion tons annually. Concrete, with the development of technology, has undergone several changes not only in its composition, but also in its performance and application. The versatility and mouldability of this material, its high compressive strength and the discovery of reinforcing and prestressing techniques which help to make up for its low tensile strength has contributed largely to its wide spread use. We can rightly say that we are in the age of concrete.

It is easy to make concrete. Extensive research works were carried out almost from the beginning of this century, not only on the methods but also on the materials used for concrete making. Still, not many men on the job seem to make use of the known techniques and materials for making good concrete, which is necessary for achieving strong, durable and economic construction.

Concrete is a man-made rock, consisting mainly of aggregates dispersed in a hydrated cement paste. Aggregates are the important constituents in concrete. They give body to the concrete, reduce shrinkage and effect economy. Aggregates occupy 65-80 percent of the volume of concrete. Aggregates are mostly natural rocks, either crushed or collected as gravel from rivers or as slag from volcanic rocks and then processed (i.e., washed and graded) for use in concrete. Aggregates can be classified on the basis of size as coarse aggregate and fine aggregate. The aggregate most of which is retained on 4.75mm IS sieve and contains not more than 0 to 10% of finer material is known as coarse aggregate. Broken stone or crushed rock is generally used as coarse aggregate. Aggregate passing through 4.75mm IS sieve and retained on 0.15mm IS sieve is called fine aggregate. Usually we use river sand as fine aggregate, but nowadays other materials like pit sand, M-sand etc. are also used abundantly in the field of construction.

B. Objectives of the Study

The main objective of this project is a study on the viability of using WEATHERED CRYSTALLINE SAND as fine aggregate. Three different types of fine aggregates are used for the test. They are River sand, M-sand and Weathered Crystalline sand. The first two types of fine aggregates are widely used in construction fields nowadays. The third one is the proposed fine aggregate. The comparison of various properties of M-sand and Weathered Crystalline sand with properties of River sand is also done. The tests conducted are grain size analysis, specific gravity test, workability test, bulk density, bulking of fine aggregate, compressive strength of mortar cube and compressive strength of concrete cube by using each type of sand. To determine the components of the weathered crystalline rock, X-Ray Fluorescence Spectrometry Analysis (XRF Analysis) is conducted.

C. Scope of the Study

The scope of the study is limited to investigate the suitability of Weathered Crystalline Sand as fine aggregate by conducting tests on grain size, specific gravity, workability, bulk density, bulking of fine aggregate, compressive strength of mortar cube and compressive strength of concrete cube. Nine mortar cubes were cast by using each variety of sand. Also nine concrete cubes were cast by using each variety of sand. To determine the components of the weathered crystalline rock, X-Ray Fluorescence Spectrometry Analysis (XRF Analysis) was conducted in the X-ray Fluorescence Lab, Centre for Earth Science Studies, Akkulam, Trivandrum.

D. Weathered Crystalline Rock

Weathered Crystalline Rocks are metamorphic rocks seen in the tropical areas like Kerala. They are formed by the weathering action on the rocks. Weathered crystalline rock is the outer layer of the underlying hard rock. Hence excessive mining is not required to obtain these types of rocks. In Kerala, weathered crystalline rock is used for the construction of small compound walls instead of random rubble and laterite bricks.

II. MATERIALS USED IN THE STUDY

A. General

The ingredients of concrete are cement, coarse aggregate, fine aggregate and water. The physical and chemical properties of each of the ingredients have considerable role in the desirable properties of concrete like durability, strength and workability. Hence special care has been taken in the selection of each of the ingredients. The following section gives an account of the materials used in this study.

B. Cement

Portland Puzzolana Cement conforming to IS 1489-1991 was used for the study. This grade was selected due to the fact that, it is the most commonly used grade of cement for construction works in Kerala.

C. Fine Aggregate

Fine aggregate fills the voids between coarse aggregates. The properties required for good quality fine aggregates are mentioned in IS 383-1970. Three different types of natural fine aggregates used in the study are mentioned below.

1. River sand. 2. M- sand and 3. Weathered crystalline sand.

D. Coarse Aggregate

Coarse aggregate is considered to be the strongest and least porous component of concrete. It is also a chemically inert material. Locally available crushed granite aggregate of 20mm down size conforming to IS 383-1970 was used.

E. Water

Water is an important ingredient of concrete, as it actively participates in chemical reaction with cement. The strength of cement concrete comes from the bonding action of the hydrated cement gel. In the present investigation, potable water was used for mixing and curing.

III. TESTING OF MATERIALS

A. General

The material properties like fineness, specific gravity, bulking of sand, bulk density and workability were tested using each type of fine aggregates. To determine the components of the weathered crystalline rock, X-Ray Fluorescence Spectrometry Analysis (XRF Analysis) was done. The experiments conducted are explained below.

XRF Analysis

The chemical compositions of rocks are used to solve numerous geological problems, including crystallization history of igneous bodies such as granite or basalt, processes of formation of the sea floor, nature of chemical weathering in various climates, stratigraphic correlation of sedimentary and volcanic rocks, processes of ore generation, and many others. Most rocks are composed primarily of silicate minerals, and over 90% of the composition of most silicate rocks can be characterized by oxides of Si, Ti, Al, Fe, Mg, Ca, Na and K. Minor and trace elements present in rocks include practically every other element, many of which are especially useful for geochemical modeling of geological processes.
Foresite now has the capability to analyze lead free processed assemblies for RoHS directive compliance utilizing XRF (X-ray Fluorescence) analysis. Utilizing Fischerscope XRF XDAL system, Foresite can examine assemblies with 0.2 mm focal distance. This system is capable of performing both quantitative elemental analysis and thickness measurements in an integrated fashion. It is able to examine each component on an assembly individually through a small spot analysis method. Looking at each layer individually, our XRF XDAL system is able to provide a meaningful and accurate measure of the RoHS compliancy of a product.

B. Sieve Analysis

To determine the particle size distribution of the fine aggregate, fineness modulus, effective size and uniformity coefficient sieve analysis is conducted. The apparatus consists Indian standard sieves (4.75mm, 2.36mm, 1.18mm, 600microns, 300 microns, 150 microns) and sieve shaker.

C. Specific Gravity of Fine Aggregates

This experiment is conducted to determine the specific gravity of given sample of fine aggregates. The apparatus used are balance, oven, pycnometer, tray, an air tight container, filter papers and funnel.

D. Bulking of Fine Aggregates

This experiment is conducted to study the behavior of sand grains under varying percentage of moisture content. The apparatus used are, a 250 ml measuring cylinder, weighing balance etc.
A graph is drawn with % water content along X-axis and % bulking along Y-axis. From graph, pick out maximum % of bulking occurred, % of water content at maximum bulking, % of water content when bulking is zero and % of bulking for the initial water content (w) of the sample.

E. Bulk Density and Percentage of Voids

This test was conducted to determine the bulk density and percentage voids of aggregate

TABLE: 1
NOMINAL CAPACITY OF METAL MESH WITH RESPECT TO SIZE OF LARGEST PARTICLE

Size of largest particle	Nominal capacity
4.75 mm and under	3 liters
Over 4.75 mm to 40 mm	15 liters
Over 40 mm	30 liters

F. Slump Test

a. General

Slump test was done to determine the workability (consistency) of prepared concrete and to check the uniformity of concrete. The slump (vertical settlement) measured was recorded in terms of milliliters of subsidence of the specimen during the test. The apparatus used for the test were, mould for slump test, non porous base plate, measuring scale and tamping rod .The mould for the test is in the form of the frustum of a cone having height 30 cm, bottom diameter 20 cm and top diameter 10 cm. the tamping rod is of steel 16mm diameter and 60 cm long and rounded at one end.

b. Method of calculating quantity of materials

In the case of M_{20} concrete For 50 kg of cement, 250 kg (coarse aggregate + fine aggregate) & 30 litres of water are required.

Coarse aggregate + fine aggregate	= 250 kg
Proportion of fine: coarse aggregate	= 1:2
Quantity of fine aggregate	= 250 x (1/3) = 83.33kg
Quantity of coarse aggregate	= 250 x (2/3) = 166.66 kg
Quantity of water	= 30 litres
Water cement ratio	= 30/50
	= 0.6
Therefore the proportion	= 50:83.33:166.66:30
	= 1:1.66:3.33:0.6
The sum of parts by weight	= 1+1.67+3.33+0.6 = 6.6

c. Quantity of materials required for 1m^3 of concrete

Weight of 1m^3 of concrete	= 2400 kg
Weight of cement required	= 2400 x (1/6.6) = 363.63 kg
Weight of fine aggregate required	= 2400 x (1.67/6.6) = 607.27 kg
Weight of coarse aggregate required	= 2400 x (3.33/6.6) = 1210.91 kg
Quantity of water required	= 2400 x (0.6/6.6) = 218.18 kg

d. Volume of frustum of a cone

Volume = $(1/3)\pi R^2 H - (1/3)\pi r^2 (H-h)$, where

R = 10 cm, H = 60 cm, h = 30 cm r = 5 cm

By substituting these values and taking 20% volume extra we get,

Volume, V = 0.006588M

e. Quantity of materials required for 0.006588m^3 of concrete

Weight of cement required	= 363.63 x 0.006588 = 2.4 kg
Weight of fine aggregate required	= 607.27 x 0.006588 = 4.0 kg
Weight of coarse aggregate required	= 1210.91 x 0.006588 = 7.98 kg
Quantity of water required	= 218.18 x 0.006588 = 1.44 kg

IV. TESTING OF SPECIMENS

A. General

The test was conducted on hardened mortar and hardened concrete after required curing. The compressive strength of mortar cubes after 3 days, 7 days and 28 days curing and the compressive strength of concrete cubes after 7 days, 14 days and 28 days curing were tested. The new fine aggregate used was expected to give sufficient strength to the specimen. This section gives an account of the various tests conducted on hardened mortar cubes and concrete cubes.

B. Compressive Strength of Mortar Cubes

The testing of mortar cubes were carried out in a compression testing machine as per IS 4031, 269, 12269, 516 guidelines. The bearing surfaces of the testing machine was wiped clean and any loose sand or other material was removed from the surfaces of the specimen. In the case of cubes, the specimen was placed in the machine in such a manner that the load was applied to opposite sides of the cube as cast, i.e. not to the top and bottom. The axis of the specimen was carefully aligned with the centre of thrust of the spherically seated platen. No packing was used between the faces of the test specimen and the steel platen of the testing machine. As the spherically seated block is brought to bear on the specimen, the movable portion was rotated gently by hand so that uniform seating was obtained. The load was applied without shock and increased continuously at the rate of approximately 350kg/cm^2/minute until the resistance of the specimen to the increasing load breaks down and no greater load can be sustained. The maximum load applied to the specimen was then recorded and the appearance of the mortar cube and any unusual features in the type of failure were noted. The measured compressive strength of the specimen was calculated by the formula,

Compressive strength = Load in N / Area in mm^2

Range calculation:

Size of the cube	= 7.05cm x 7.05cm x 7.05cm
Area of specimen (from the mean size of the specimen)	= 50cm^2 = 5000mm^2
Expected load (stress x area x factor of safety)	= 53x5000x1.5 = 397500 N = 397.5kN

Range to be selected is 0-500kN

C. Compressive Strength of Concrete Cubes

The concrete cubes were tested in a compression testing machine as per IS 516 guidelines. The bearing surfaces of the testing machine was wiped clean and any loose sand or other material removed from the surfaces of the specimen. The specimen was placed in the machine in such a manner that the load was applied to opposite sides of the cube as cast, i.e. not to the top and bottom. The axis of the specimen was carefully aligned with the centre of thrust of the spherically seated pattern. No packing was used between the faces of the test specimen and the steel platen of the testing machine. As the spherically seated block was brought to bear on the specimen, the movable portion was rotated gently by hand so that uniform seating was obtained. The load was applied without shock and increased continuously at the rate of approximately 140kg/cm^2/minute until the resistance of the specimen to the increasing load breaks down and no greater load could be sustained. The maximum load applied to the specimen was then recorded and the appearance of the concrete cube and any unusual features in the type of failure were noted. The measured compressive strength of the specimen was calculated by the formula,

Compressive strength = Load in N / Area in mm^2

Range calculation:

Size of the cube	= 15cm x 15cm x 15cm
Area of specimen (from the mean size of the specimen)	= 225cm^2 = 22500mm^2
Characteristic compressive strength (f_{ck}) at 28 days	= 20N/mm^2
Expected maximum load (stress x area x f.s.)	= 20x22500x1.5 = 675kN

Range to be selected is 0-1000kN

V. RESULTS AND DISCUSSION

A. General

The tests on grain size, specific gravity, workability, bulk density, bulking of fine aggregate, compressive strength of mortar cube, compressive strength of concrete cube and XRF Analysis were conducted. Nine mortar cubes were cast by using each variety of sand. Also nine concrete cubes were cast by using each variety of sand. That is total 27 mortar cubes and 27 concrete cubes. To determine the components of the weathered crystalline rock, X-Ray Fluorescence Spectrometry Analysis (XRF Analysis) was conducted in the X-ray Fluorescence Lab, Centre for Earth Science Studies, Akkulam, Trivandrum.

ISSN: 2319-8753

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Vol. 2, Issue 4, April 2013

B. XRF Analysis

Table: 2
RESULT OF XRF ANALYSIS –MAJOR ELEMENTS

SiO_2	67.55%
TiO_2	0.66%
Al_2O_3	16.07%
MnO	0.04%
Fe_2O_3	3.81%
CaO	2.12%
MgO	0.71%
Na_2O	2.68%
K_2O	5.76%
P_2O_5	0.33%

Table:3
RESULT OF XRF ANALYSIS –TRACE ELEMENTS

V(PPM)	35
Cr(PPM)	82
Co(PPM)	3
Ni(PPM)	5
Cu(PPM)	4
Zn(PPM)	43
Ga(PPM)	20
Rb(PPM)	189
Sr(PPM)	232
Y(PPM)	68
Zr(PPM)	516
Nb(PPM)	12
Ba	0.13%
La(PPM)	89
Pb(PPM)	26
Ce(PPM)	145
Sm(PPM)	10

Chemical combination of the weathered crystalline rock is almost similar to the chemical combination of natural occurring rocks. The silica is the major constituent in natural sand, in the case of weathered crystalline rock silica constitutes the major part about 60-70% which determines the strength parameter, being strength is the major concern regarding the material as a fine aggregate. Other constituents like oxides of Manganese, Magnesium, Iron, Aluminum etc. are in the safe limits. Other trace elements are in the range of ppm those are not at all affects the chemical activity of fine aggregate.

C. Grain Size Analysis

Table: 4
RESULT OF GRAIN SIZE ANALYSIS

SL. NO.	NAME OF THE SAMPLE	UNIFORMITY CO-EFFICIENT	FINENESS MODULUS
1	River sand	2.34	5.78
2	M sand	5.78	2.93
3	Weathered crystalline sand	4.17	3.11

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Vol. 2, Issue 4, April 2013

As per IS specification, value of fineness modulus of fine aggregate lies between 2 and 3.5

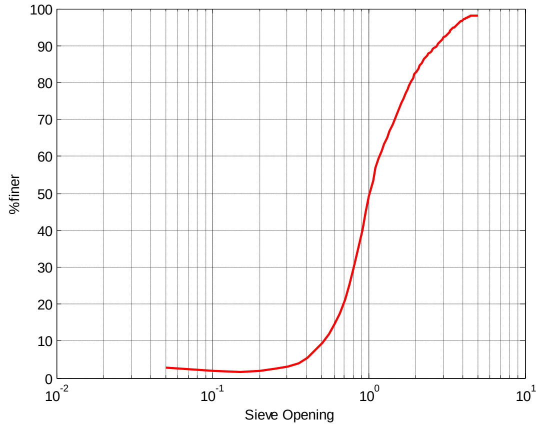

Fig: 1 Semi log graph plotted for river sand

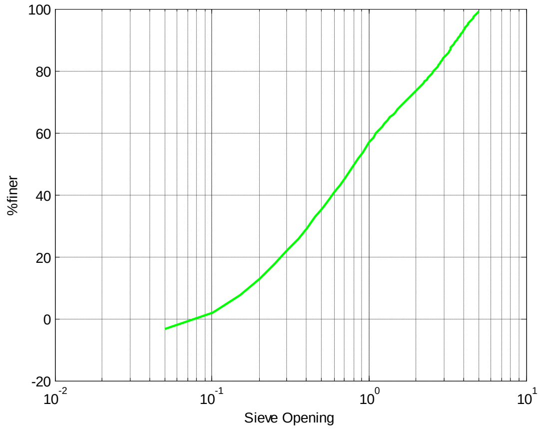

Fig: 2 Semi log graph plotted for M- sand

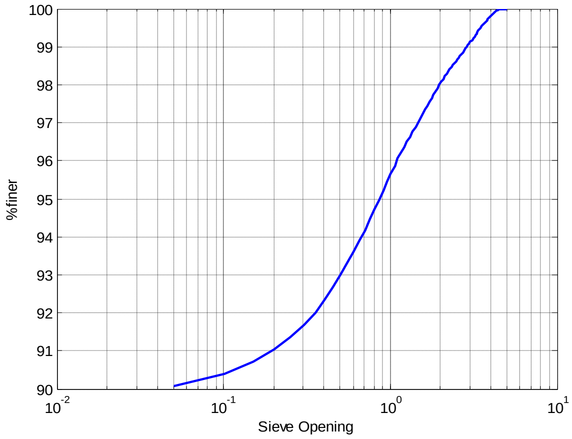

Fig: 3 Semi log graph plotted for weathered crystalline sand

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Vol. 2, Issue 4, April 2013

D. Specific Gravity

Table: 4
RESULT OF SPECIFIC GRAVITY

SL. NO.	NAME OF THE SAMPLE	SPECIFIC GRAVITY
1	River sand	2.5
2	M sand	2.68
3	Weathered crystalline sand	2.73

According to IS 2386 (Part III), the specific gravity of fine aggregate should lie between 2.6 and 2.8

E. Bulking of Sand

Table: 5
RESULT OF BULKING OF SAND

SL. NO.	NAME OF THE SAMPLE	PERCENTAGE OF BULKING
1	River sand	17.85
2	M sand	15.47
3	Weathered crystalline sand	15.95

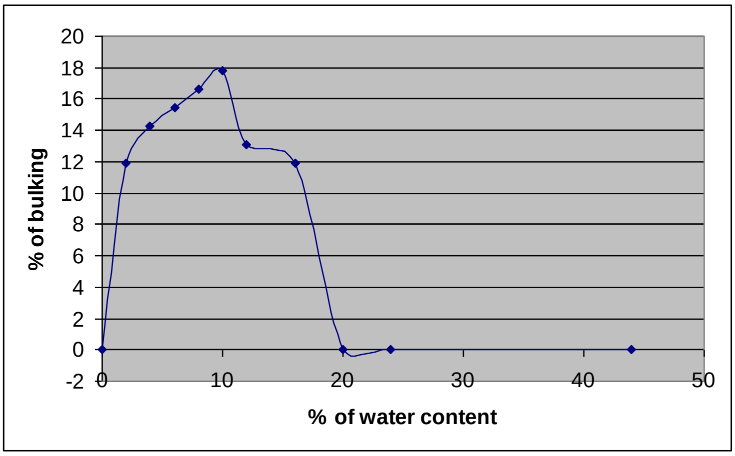

Fig: 4 Bulking of River sand

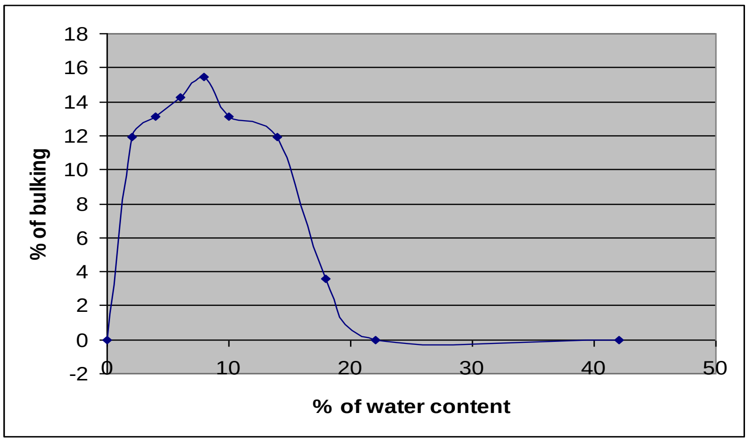

Fig: 5 Bulking of M-sand

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Vol. 2, Issue 4, April 2013

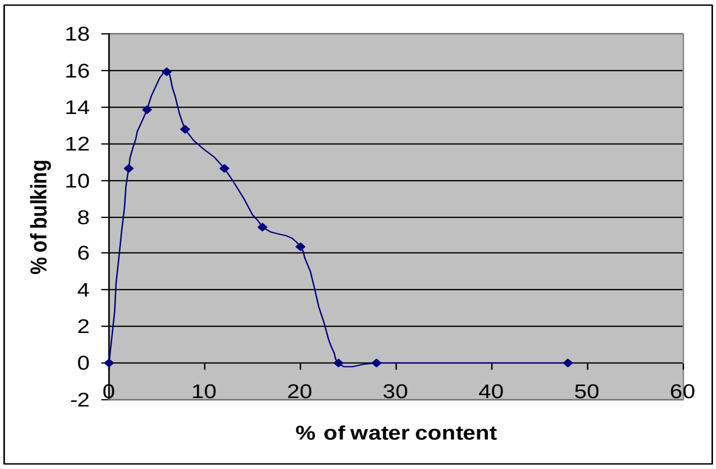

Fig: 6 Bulking of Weathered crystalline sand

Bulking of fine aggregate ranges from 15-30%

F. Bulk Density

Table: 6
RESULT OF BULK DENSITY

SL. NO.	SAMPLE	BULK DENSITY (Kg/l)	PERCENTAGE VOIDS
1	River sand	1.47	41.4
2	M sand	1.59	40.67
3	Weathered crystalline sand	1.57	42.49

Bulk density of fine aggregate is between 1.45 kg/l and1.65 kg/l.

G. Workability

Table: 7
RESULT OF WORKABILITY

SL. NO.	SAMPLE	SLUMP (mm)	DEGREE OF WORKABILITY
1	River sand	30	Low
2	M sand	29	Low
3	Weathered crystalline sand	26	Low

The workability of the given mix is low. This slump is suitable for mass concrete, lightly reinforced sections in slabs, beams, walls etc.

H. Compressive Strength of Mortar Cubes

Table: 8
COMPRESSIVE STRENGTH OF MORTAR CUBES

SL. NO.	SAMPLE	AFTER 3 DAYS (N/mm^2)	AFTER 7 DAYS (N/mm^2)	AFTER 28 DAYS (N/mm^2)
1	River sand	13.33	20.40	36.13
2	M sand	9.47	12.80	27.33
3	Weathered crystalline sand	8.13	18.53	30.40

Minimum compressive strength of mortar cubes after 3 days, 7 days and 28 days should be 16N/mm^2, 22N/mm^2 and 33N/mm^2 respectively.

I. Result of Compressive Strength of Concrete Cubes

Table: 9
COMPRESSIVE STRENGTH OF CONCRETE CUBES

SL. NO.	SAMPLE	AFTER 7 DAYS (N/mm^2)	AFTER 14 DAYS (N/mm^2)	AFTER 28 DAYS (N/mm^2)
1	River sand	16.20	21.20	24.96
2	M sand	16.60	20.60	22.81
3	Weathered crystalline sand	16.30	22.30	25.78

Compressive strength of concrete cubes after 28 days should be 20N/mm^2 and its 2/3rd strength should be attained in their early stages.

VI. CONCLUSIONS

- Weathered crystalline sand is suitable for construction works instead of M-sand.
- Extensive mining is not required, since weathered crystalline rock is the outer layer of the underlying hard rock.
- Like river sand weathered crystalline sand attains strength gradually while M-sand attains its compressive strength at an earlier stage.
- More economy can be attained, as cost of weathered crystalline sand is very less as compared to river sand and M-sand.

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BIOGRAPHY

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