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Performance Appraisal of River Stone as a coarse Aggregate in Concrete

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ABSTRACT
Concrete has been proved to be a leading construction material for more than a century. The aggregate element in concrete comprises 60-75% of the total volume. Due to heavy increase in the construction activities, the crushed granite stone which are the conventional coarse aggregate is under depletion and also, now–a-days an acute shortage of these materials is experienced. Hence an alternative for the crushed granite stone has to be explored. Though the river stone has got high potential for being a natural aggregate, it is been rarely used as a concrete material. The present investigation envisages the potential utilization of river stone as a coarse aggregate in replacement of crushed stone aggregate in concrete. Concrete mixes with 0%, 25%, 50%, 75% and 100% replacement to crushed stone aggregate were considered in this study. The mix proportion is done as per IS 10262 (2009). The properties of fresh and hardened concrete were studied on the mixes considered. The results showed that there is an increase in slump value and strength properties and hence the use of river stones could be considered for future concrete.
Keywords - Aggregates; River stones; Fresh properties; Hardened properties.

I. INTRODUCTION

There is a direct relationship between population and urbanization. During the last 100 years, the world population has grown from 1.5 to 6 billion and nearly 3 billion people now live in and around the cities. Seventeen of the 20 megacities, each with a population of 10 million or more, happen to be situated in developing countries where enormous quantities of materials are required for the construction of housing, factories, commercial buildings, drinking water and sanitation facilities, dams and canals, roads, bridges, tunnels, and other infrastructure and the principal material of construction is Portland cement concrete. By volume, the largest manufactured product in the world today is concrete [1].

Concrete has replaced most of other competitive construction materials, because of its versatility, easy availability and mould arability. It is a material of choice by the architects and structural engineer with the belief that it is a durable material needing no maintenance and protection. Many concrete structures built decades back performing well even today bearing testimony for the earlier belief. Naturally, design and construction engineers need to know more about concrete than about other materials of construction [2].

Concrete is obtained by mixing cementitious materials, water and aggregate in required proportions. The mixture when placed in forms and allowed to cure hardens into rock like mass known as concrete. The hardening is caused by chemical reaction between water and cement and it continues for a long time, and consequently the concrete grows stronger with age. The hardened concrete may also be considered as an artificial stone in which the voids of larger particles are filled by the smaller particles and the voids of fine aggregate are filled with cement the importance of using the right type and quality of aggregates cannot be overemphasized. The aggregate element in concrete comprises some 60–75% of the total volume [3]. Aggregate inclusion in concrete reduces its drying shrinkage and improves many other properties. Aggregate is also the least expensive per weight unit, put it makes the most amount of the weight. The global consumption of aggregate will be in the range of 8–12 billion tones after 2010 [4].

In India, almost all the Civil Engineering constructions are carried out using crushed granite aggregate as it was available in plenty. Due to heavy increase in the construction activities, the crushed granite stone which are the conventional coarse aggregate is under depletion and also, now–a-days an acute shortage of these materials is experienced. As these aggregates have to be transported from the long distance it is also proving uneconomical. Another serious disadvantage of these aggregate is the air pollution problem generated by crushing plants.

Hence, an alternative for the crushed granite stone has to be explored.

Though the river stone has got high potential for being a natural aggregate, it is been rarely used as a concrete material. This is mainly due the lack of knowledge of its performance in concrete, lack of available standards on the use of river stones in concrete and also the presence of impurities in the material. River stones are usually found along the shores of large rivers and lakes. These stones are formed as the flowing water washes over rock particles on the bottom and along the shores of the river. The smoothness and colour of river stones depends on several factors, such as the composition of the soil of the river banks, the chemical characteristics of the water, and the speed of the current. Because river current is gentler than the ocean waves, river stones are usually not as smooth as beach stones. The most common colours of river rock are black, grey, green, brown and white.

The present investigation envisages the potential utilization of river stone as a coarse aggregate in replacement of crushed stone aggregate in concrete, which are available not only economically but locally.

A. Advantages of Uncrushed River Stone over Crushed Granite Aggregate

1. In the production of crushed aggregate, the crushing plant generates dust. This ‘fugitive’ dust, if releases in the atmosphere untreated, may pose pollution problem. Whereas, this pollution problem is not with the production of uncrushed aggregate.
2. During travel of gravels in river its sizes are reduces naturally without any micro cracking in the aggregates body or any crack and loose fragments attached in it. In fact this is not so with crushed aggregate as in mechanical crushing there are chances of attached crack and week fragments in the aggregate which may affect the strength of concrete.
3. Angular shape of crushed aggregate required more water for a given workability. Thus more cement will be required for a given water-cement ratio. More water-cement paste means less durability of concrete. Naturally formed surfaces of uncrushed aggregates from river bed improved the workability and this is advantageous in terms of reduced water demand which produces more dense, impermeable and durable concrete [5].

B. Aim of the Study

In the surrounding areas of river Payaswini in Sullia, locally available river stones have been used extensively as a road and building material (coarse aggregate in concrete). Even though, it has shown that there is no adverse effect on the performance of the concrete, there is a serious misconception that it offers less bonding property and contributes less for strength. The present investigation envisages the potential utilization of river stone as a coarse aggregate in replacement of crushed stone aggregate in concrete. The main objective of research is

i. To determine fresh and hardened properties of concrete made with river stone and to compare with those using crushed stone aggregate (traditional).
ii. To ascertain whether River stone can be a good aggregate for concrete.

With the increase in the developmental activities in the world over, the demands for the constructional materials are increasing exponentially. There are some instances that these materials are imported from other countries to create to the domestic needs. This trend will have certainly greater impact on the economy system of the country, especially in India, which is aiming at a high developmental rate comparing to the other nations in Asia, there is heavy demands for the building materials in the domestic market which is going scarce day by day. At this point researchers and engineers who have the foresight to keep the developmental activities abreast and curtail the cost factor should look out for any alternative building materials.

II. MATERIALS AND THIER PHYSICAL PROPERTIES

A. Cement

The Cement used was Portland Pozzolona Cement (PPC) manufactured by Ultratech, conforming to IS: 1489(PT1):1991[21]. The various properties of cement were in accordance with IS: 4031-1991[14] and the results are tabulated in Table 3.

Table 2.1: Properties of Pozzolona Portland Cement

Sl. No	Test		Results	IS 1489 (Part I) requirement
1	Specific Gravity		2.84	-
2	Standard Consistency (%)		33	-
3	Setting time	Initial (minutes)	45	30 (min)

		Final (minutes)	500	600 (max)
4	Compressive strength,28days(N/mm^2)		35	33
5	Fineness (m^2/kg)		380	300

B. Aggregate (Coarse and Fine Aggregate)

In this investigation, the Granite chips and locally available river stone were used as coarse aggregates and river sand was used as fine aggregate. The river stones were collected from the river Payaswini near Basmattka, Sullia, DakshinaKannada, karnataka. The aggregates were tested as per relevant IS specification (IS: 2386-1963[13], IS: 383-1970[15]) and the results are tabulated in Table 3.2 to 3.6.

Table 2.2: Sieve Analysis of Crushed Granite Aggregate

Sieve Size mm	% Weight passing	IS Code specification
40	100	Confirms to grade II (graded aggregate)
25	97.625	
20	62.625	
10	1	
4.75	0	

Table 2.3 Sieve Analysis of Fine Aggregate

Sieve Size (mm)	Percentage passing	Percentage passing for grading zone II as per IS :383-1970
4.75	100	90-100
2.36	93.25	75-100
1.18	69.75	55-90
0.6	42.25	35-59
0.3	2.25	8-30
0.150	1.0	0-10

Fineness modulus = 2.91

The taken sample confirms to grading Zone II of table 4 of IS: 383-1970[15].

Table 2.4: Physical Properties of River Stone

Sl. No.	Tests		Results	Specification
1	Specific gravity		2.63	2.6-2.8
2	water absorption		1.62%	0.6% (maximum)
3	Impact value		29.36%	45% (maximum)
4	Shape test			
	Flakiness index		18.28%	30% (maximum)
	Elongation index		18.47%	30% (maximum)

Table 2.5: Physical Properties of Granite Aggregate

Sl. No.	Tests	Results	Specification
1	Specific gravity	2.7	2.6-2.8
2	Water absorption (%)	0.45	0.6% (maximum)
3	Impact value (%)	25.25	45% (maximum)

Table 2.6: Physical Properties of Fine Aggregate

Sl.No.	Tests	Results	Specification
1	Specific gravity	2.62	-
2	Sieve analysis	Confirms to grading Zone II of table 4 of IS: 383-1970	
3	Fineness modulus	2.91	2.9 – 3.2 (Coarser sand)

C. Water

The water available in the laboratory satisfies the standard, specified for making concrete and its subsequent curing.

III. METHODOLOGY

A. Introduction

The present investigation and the comparative studies on the strength characteristics of the river stone as coarse aggregate in concrete with conventional concrete was carried out. The standard tests of all materials have been carried out in the laboratory as per the relevant codes.

B. Equipment Used

The following apparatus are used in the present investigation.

1. Regular steel moulds for cubes, beams, cast iron cylinder moulds.
2. Electrical operated table vibrator.
3. A compression testing machine of capacity 200 tones.
4. Slump cone apparatus.
5. Compacting factor apparatus.
6. Mixing tray, trowels, measuring jar, weighing balance, pans etc.

C. Moulds

Cast iron moulds confirming to IS: 516-1959 were used to cast Cube specimens of size 100mm x 100mm x 100mm. Cylinder specimens of size 100mmdia and 300mm height and Beam specimen of size 100mm x 100mm x 500mm are used.

D. Table Vibrator

A table vibrator of size 600x600mm, operated electrically has been for compacting of concrete in the moulds.

E. Testing Machine

For testing compressive strength of cubes compression testing machine of 2000KN capacity was used. It is shown in Fig4.1. The machine has been so designed to meet the simple and reliable unit having minimum weight and dimension for the above load capacity, without seated steel platen at the top and a movable steel platen at the bottom. This machine can also used for split tensile strength test.

The beam specimens are tested using hydraulically operated flexural testing machine of capacity 100KN. Load can be applied at the required rate specified in the code for different specimens. The bed of the testing machine is provided with two adjustable steel rollers 38mm in diameter on which the specimens are supported. This roller can be fixed to the bed such that the distance from center to center can be adjusted for 400mm as well as 600mm.The load can be applied through one similar roller mounted at the midpoint of the rollers[12].

F. Cleaning

River stones which are taken from the river are washed and cleaned to remove the vegetative matters and other deleterious materials adhering on it.

G. Grading

Cleaned river stones are graded to the gradation of crushed granite aggregate as per Table 3.2.

H. Presoaking

The Water absorption of river stone was found to be more than 1.5%. Hence to make the aggregate saturated surface dry condition, it is presoaked prior to mixing. In presoaking, graded river stones were immersed in water for 30 minutes as the absorption of river stone in first 30 minutes will reach about 90% of its maximum capacity. The fully saturated aggregates were then taken out of the water, and surface dried [10, 11].

IV. MIX DESIGN

In this investigation M30 grade was considered and designed using a procedure by IS: 10262-2009[18]. After considering many trial mixes, the mix proportions for control concrete were as 1:1.65:2.82 with water cement ratio of 0.48. The calculation of quantities of ingredient require for different concrete mixes are given in Appendix-I. The Batch identification and their respective bulk composition is as shown in table 4.1.

4.1: Batch ID and Bulk Composition

Batch ID B	RS:SA RS : SA	Bulk Composition in kg/m^3					w/c Ratio
		cement	Fine Aggre	RS	SA	water Water	
R0	0:100	399.125	659.04	0	1127.13	191.58	0.48
R25	25:75	399.125	659.04	281.78	845.34	191.58	0.48
R50	50:50	399.125	659.04	563.56	563.56	191.58	0.48
R75	75:25	399.125	659.04	845.34	281.78	191.58	0.48
R100	100:0	399.125	659.04	1127.13	0	191.58	0.48

A. Mixing Procedure

The fine aggregate was sieved through 4.75 mm IS sieve. The required quantities (as per mix proportion) of different ingredients were weighed and kept separately.

The mixing procedures for making different grades of concrete are as follows:

1) First cement and sand were mixed thoroughly.
2) Coarse aggregate was then added to the mix and mixed thoroughly until the mixture is of uniform colour.
3) The water is added and mixed thoroughly until the mix is uniform consistency [8].

B. **Casting of Test Specimens**

For particular day, mixes were prepared so as to enable the casting of 9 cubes, 3 cylinders and 3 beams as given in Table 4.2, which comprises one set. Mean while the moulds were cleaned, oiled, assembled rigidly and kept ready for concreting.

Weighed quantities of coarse and fine aggregate and cement poured in steel tray and mixed thoroughly until the mixture is of uniform colour. The measured quantity of water is added and mixed thoroughly until mix is uniform consistency. The moulds are first placed on table vibrator. The concrete is then poured into the moulds and compacted using table vibrator. After the concreting and compaction the upper surfaces are finished smooth with mason's trowel and corresponding identification marks are labeled over the finished surface. It is worthwhile to note that the concreting operation is completed within 25 to 30 minutes from the instance of adding water to the dry mix. The moulds are left undisturbed in the laboratory for a period of 24 hours. Similar procedure has been adopted for subsequent concreting and casting operation on the other days.

Table 4.2: Total Number of Specimens Produced Under the Present Investigation

Mix (30)	Mix Designation	Combination of coarse aggregates (Granite	Total number of elements cast		
			Cubes	Cylinders	Prisms
PP C	R0	100:0	9	3	3
	R25	75:25	9	3	3
	R50	50:50	9	3	3
	R75	25:75	9	3	3
	R10 0	0:100	9	3	3

C. Curing of Test Specimens

As described in the previous section the concrete specimens were kept at room temperature in laboratory for 24 hours. Later the specimens were demoulded and were transferred into the curing tank. The temperature of the water in the curing tank is maintained with 27 °c on an average.

V. TESTS ON FRESH CONCRETE AND HARDENED CONCRETE

A. Fresh Concrete

Concrete mixes prepared were tested for its fresh properties like workability such as slump test and compaction factor test.

B. Slump test

Slump test is a most commonly used method of measuring the consistency of the concrete which can be employed either in laboratory or at site of work. It is used to conveniently as a control test and gives an indication of the uniformity of concrete from batch to batch. Additional information on workability and quality of concrete can be obtained by observing the manner in which concrete slumps. The deformation shows the characteristic of concrete with respect to tendency for segregation [9].

C. Compacting factor test

The compacting factor test is designed primarily for use in the laboratory but it can also be used in the field. It is more precise and sensitive than the slump test and is particularly useful for concrete mixes of very low workability as are normally used when concrete is to be compacted by vibration. Such dry concrete are insensitive to slump test.

D. Hardened concrete

Testing of hardened concrete plays an important role in controlling and confirming the quality of cement concrete work. For efficient structure design to be presented, knowledge of properties of hardened concrete is to be known clearly. In the present investigation, hardened properties such as compressive, split tensile and flexural strength are determined.

E. Compression test on concrete

The most common of all tests is the compressive strength test since the desirable characteristics of concrete are qualitative related to its strength.

The compression test was conducted on cubes at the age of 7 days, 28 days and 45 days of curing respectively and confirming to IS 516-1959[17]. Cubes stored in water were tested immediately on removal from water in the damp condition. The surface water and grit was wiped off from the specimen. The actual dimensions and weight of the specimen was noted. The specimen was placed on the testing platform of the compression testing machine in such way the load was applied to the surface other than the top and bottom surface as cast. The load was applied without shock and increase until the resistance of the specimen to the increasing load broke down and no greater load was sustained. The total load applied at failure was recorded. The maximum load applied divided by its cross sectional area given the compressive strength. Averages of three specimens were taken, provided the individual variation was not more than ± 15 percent of the average [9]. Testing of specimen is shown in Figure 4.1.

Fig. 4.1: Compression Testing Machine

F. Centre –point flexural test on beams

The theoretical maximum tensile stress reached in the bottom fiber of the test beam is known as the modulus of rupture. This value depends on dimension of the beam and arrangement of loading.

The test was performed as per IS: 516-1959[17] specification on beams of 100mm ×100mm×500mm with an effective span of 400mm. the specimen was placed in the hydraulically operated beam testing machine in such a manner that the load applied to the finished surface, as cast in the mould. The rate of loading was kept at 18 kg/minute and the modulus of rupture is calculated by the relation [9].

The flexural strength of the specimen is expressed as the modulus of rupture f_b which if 'a' equal the distance between the line of fracture and the nearer support, measures on the centre line of the tensile side of the specimen, in cm, is calculated to the nearest 0.05 MPa as follows:

$$f_b = P*L/b*d^2$$

when 'a' is greater than 20.0 cm for 15.0 cm specimen or greater than 13.3 cm for a 10.0 cm specimen, or

$$f_b = 3p*a/b*d^2$$

when 'a' is less than 20.0cm but greater than 17.0 cm for 15.0 cm specimen, or less than 13.3cm but greater than 11.0cm for a 10.0 cm specimen where
b=measured width in cm of the specimen,
d=measured depth in cm of the specimen at the point of failure,
L= length in cm of the span on which the specimen was supported, and
P= maximum load in kg applied to the specimen.

If 'a' is less than 17.0 cm for a 15.0 cm specimen, or less than 11.0 cm for a 10.0 cm specimen, the result of the test discarded. Testing of specimen is shown in Figure 4.2.

Fig. 4.2: Flexural Strength Testing Machine

G. Test for split tensile strength

This is also known as "Brazilian test". It is an indirect method of applying tension in the form of splitting. The specimen is placed with its axis horizontal between the platens of a testing machine. Thin strips of 10mm width, 3mm thick and 300mm long are inserted between the cylinder and the platen of test machine. The specimens are tested in wet condition, 2000KN compression testing machine as per the code of practice IS: 5816-1970[20]. The load is increased at the rate of 14N/mm^2/min until failure by splitting along the vertical diameter has taken place [9].

The split tensile strength (f_{st}) is given by the relation

$$f_{st} = 2 P/ (\pi Ld)$$, Expressed as N/mm^2

Where,
P=failure load, in N
L= length of cylinder, in mm
D = Diameter of cylinder, in mm

Testing of specimen is shown in Fig 4.3.

Fig. 4.3: Cylinder Specimen under Split Tensile Test

VI. RESULTS AND DISCUSSION

General

Detailed experimental investigations were carried out on the effect of river stone replacing granite aggregate in concrete. The experimental results were discussed in the following sections.

A. Physical Properties of Specimen

1. Dimensions of the Specimen

The dimensions of the all types of specimens were found to be within the tolerance limits specified in the relevant IS codes (IS: 516-1959[17], IS: 5816-1970[20]). The specimens revealed excellent physical appearance without honeycombing or any defect and they were found to be uniform.

2. Density of the Specimens

The densities of different specimens are evaluated based on size of the specimen; the results are tabulated in Table 5.1.

Table 5.1: Density of the Specimens

Batch Id	Density kg/m^3
R0	2426.7
R25	2416.67
R50	2400.0
R75	2455
R100	2406.67

3. Fresh Properties of Concrete Mixes

Workability of concrete mixes increased with the increase in percentage of river stone in concrete. The slump value of the concrete made using only crushed granite aggregate was found to be 15mm, which is very low (IS 456:2000[16]). The high friction caused by the rough texture and the angular shape of the crushed granite aggregate was thought to be the main reason for low slump. As the percentage of river stone increases, the slump value increased and it was high about 120mm when crushed granite aggregate was completely replaced by river stone. This is because of smooth texture, round shaped aggregate contributing low friction in the concrete mix and thus increased workability. Similar behavior was observed in compaction factor values, where it ranged from 0.90 to 0.956 for R0 to R100 mix respectively. The results of slump and compaction factor are tabulated in Table 5.2. The variation of Slump values and Compaction factor for various concrete mixes are illustrated in Fig 5.1 and 5.2.

If the workability had kept constant say medium (50 to 75mm) the water content for R75, R100 can be reduced; this reduction in water content would be an additional benefit for mechanical properties of concrete.

Table 5.2: Slump and Compaction Factor Values

Batch Id	Slump in mm	Compaction factor
R0	30	0.90
R25	45	0.93
R50	60	0.948
R75	90	0.950
R100	120	0.956

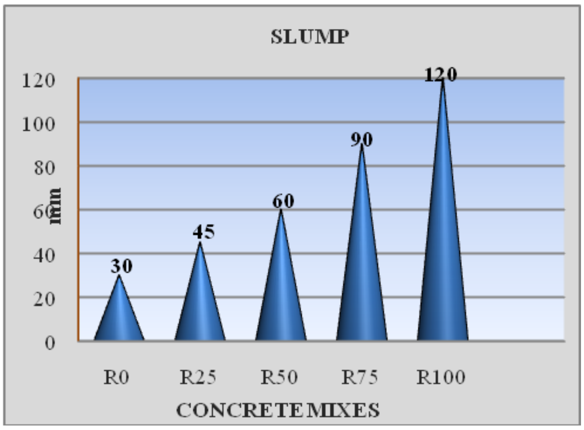

Fig. 5.1: Variation in slump values

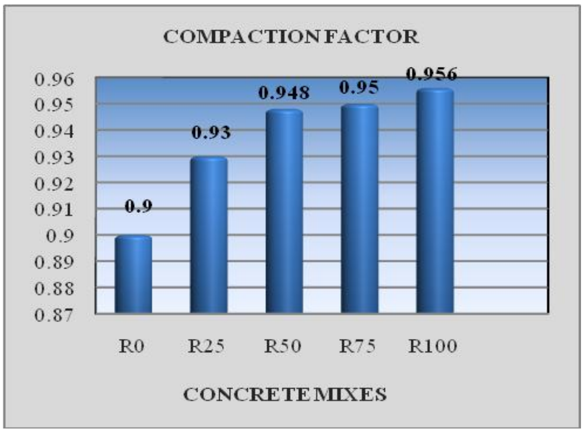

Fig 5.2: Variation in Compaction factor

B. Mechanical Properties of Specimen

1. Cube Compression Strength Results

The compression strength test result for various concrete mixes is tabulated in Table 5.3, after curing period of 7, 28, 45 days. The value ranges from 35 to 31.5 for R0 to R100 respectively for 28 days. Fig 5.3 clearly showed that 7, 28 & 45 days compressive strength decreased gradually as percentage of river stone increased.

Table 5.3: Results of Compressive strength for various concrete mixes

Batch ID	Days	Compressive strength in MPa	Rate of attainment of strength in %
R0	7	26.267	66.76
	28	35	100
	45	45	128.57
R25	7	25.5	67.97
	28	33.67	100
	45	42.33	125.72
R50	7	24.74	67.94
	28	32.67	100
	45	38	116.31
R75	7	23	61.61
	28	31.83	100
	45	35.83	112.56
R100	7	20.17	43.83
	28	31.5	100
	45	34	107.93

The reduction of strength of concrete at 28 days was found to be 3.95, 7.13, 9.96 &11.11 % for R25, R50, R75 and R100 concrete mixes respectively. This could to be due to surface texture of aggregate particles which largely determines the strength of bond between the cement paste and aggregate surface. A rough surface creates a good bond where as smooth surface does not [1].

It was observed that, the failure of the Granite stone concrete was due to the aggregate failure, whereas the failure in the river stone concrete occurred at the aggregate –mortar matrix bonding interface.

Rate of attainment of strength for various concrete mixes are tabulated in Table 5.3. It was observed that rate of strength attained by control mix from 7th day to 28 days was 33.24%, whereas for R100 it was found to be 56.17%, which was very much higher than the control mix. However the rate of strength attainment for R100 concrete mix was decreased after 28 days. At 45th day the strength increased at a rate of 28.57% for R0 concrete mix and for R100 concrete mix only 7.93% strength was increased. This indicates that the inclusion of river stone hampers the long term strength of the concrete. Variations of rate of attainment of strength of various concrete mixes are illustrated in fig 5.4.

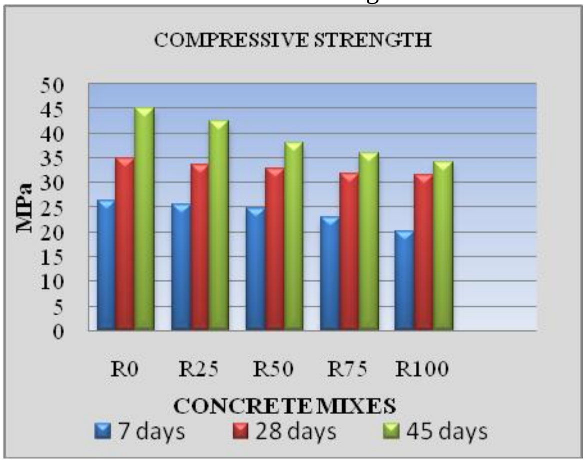

Fig. 5.3: Compressive Strength Development of Various Concrete Mixes Made Using PPC at Different Curing Periods

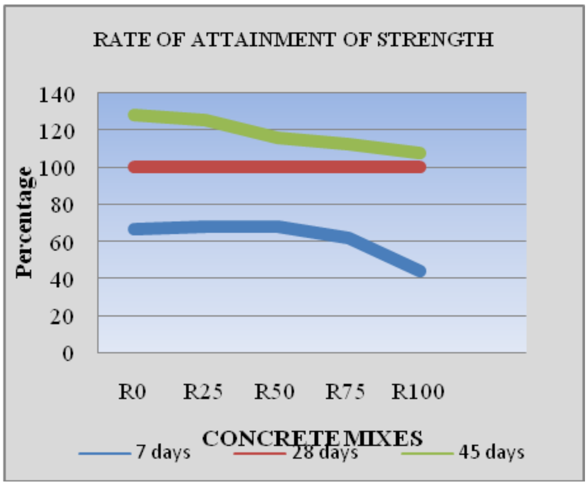

Fig. 5.4: Rate of Attainment of Compressive Strength for Various Concrete Mixes.

2. Flexural Tensile Strength

The flexural tensile strength test result for various mixes is tabulated in Table 5.4. for curing period of 28 days. The flexural tensile strength of beam specimen varies from 3.11 MPa to 2.38 MPa for R0 to R100 respectively. Result showed that addition of higher percentage of river stone will decrease the strength. This may be attributed to the smooth surface of the river stones, resulting in lower bonding strength with the matrix. However the values of concrete made with river stone were comparable to the control mix. The variation in flexural tensile strength with varying percentage of River Stone is illustrated in Figure 5.5. The beam specimens were failed due to development of breakage on the surface.

5.4: Test Result for Flexural Tensile Strength of Concrete Beams

Batch ID	Days	Flexural strength in MPa
R0	28	3.11
R25	28	2.87
R50	28	2.95
R75	28	2.74
R100	28	2.38

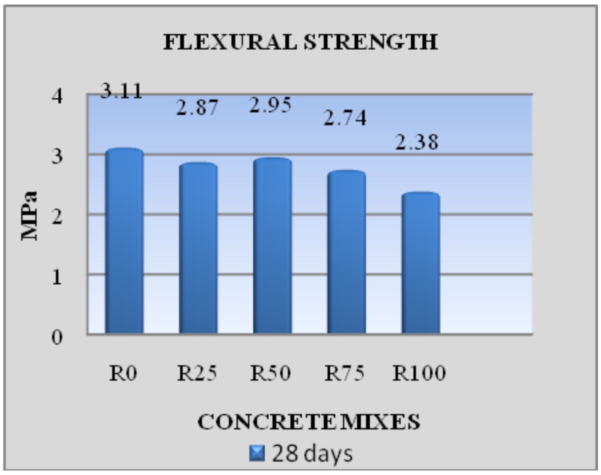

Fig. 5.5: Flexural Strength at 28 Days for Various Concrete Mixes

3. Split Tensile Strength

From the results of compressive strength and flexural strength, reduction in strength was observed. Similar trend is also valid for split tensile strength. The test result for various mixes is tabulated in Table 5.5 for curing period of 28 days. The split tensile strength of cylinder specimen varies from 2.49 MPa to 2.06 MPa for R0 to R100 respectively. Two different failure modes could be observed in split testing of cylinders. In case of crush granite aggregates, the aggregate particles were found to split so as to form two equal halves. Whereas in river stone failure occurred at the aggregate –mortar matrix boding interface. The variation in split tensile strength with varying percentage of RS is illustrated in fig 5.6.

Table 5.5: Test Results of Split Tensile Strength Of Cylinders

Batch ID	Days	Tensile strength in MPa
R0	28	2.49
R25	28	2.22
R50	28	2.18
R75	28	2.12
R100	28	2.06

VII. CONCLUSION

1) Workability of the concrete mixes increased with the increase in the percentage of river stones. This is mainly because of the smooth surface and round shape of the river stone. If the workability had kept constant, the water content for some of the concrete mixes could have been reduced thus benefiting the mechanical properties of concrete.
2) Concrete made with river stone gains strength at the higher rate up to 28 days than the granite aggregate concrete but beyond 28 days there was a reduction in the rate of gain in strength of river stone concrete.
3) The compressive strength for river stone concrete found to be less than crushed granite aggregate made from similar mix proportion. However, the compressive strength of the concrete mixes made using river stone exceeds the design strength of the concrete.
4) The flexural tensile strength test result showed that addition of higher percentage of river stone will decrease the strength. This may be attributed to the smooth surface of the river stones, resulting in lower bonding strength with the matrix.
5) The split tensile strength of cylinder specimen decreased with the increase in the percentage of river stone in concrete.
6) Two different failure modes could be observed in split tensile testing of cylinders. In case of crush granite aggregates, the aggregate particles were found to split so as to form two equal halves. Where as in river stone, failure occurred at the aggregate– mortar matrix bonding interface.
7) Even though the mechanical properties of concrete made using river stone decreased it was comparable with the standard aggregate concrete. Thus it can be concluded that the river stone which is abundantly available locally can be efficiently used as a coarse aggregate in concrete.

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