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Mechanical Strength Properties of Geo Polymer Concrete incorporating Quarry Rock Dust and Recycled Coarse Aggregate

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Abstract*: Utilization of waste materials in concrete are increasing day by day. Ingredient replacements in concrete using waste materials are one of such threads which bind nature and concrete in a greener way to provide a better environment for the future. Reduction in environmental pollution, effective usage of waste management, the economic factor and quality of concrete are the predominant aspects by which the replacement materials are chosen.[1] Geopolymer Concrete has emerged as one of the possible alternatives to OPC, since 100% of fly ash is used instead of Portland Cement.. In this present study, the prime material which is used as the source material is fly-ash (ASTMC618) which completely replaces cement..Also fine aggregate has become very expensive and scarcity, quarry rock dust have been replaced for fine aggregate. Almost all the demolition and construction waste have been dumped without any usage which ultimately results in pollution.[2] This prime factor is considered to reutilize recycled coarse aggregate instead of coarse aggregate . A greener aided with natural friendly claim can be made only with the usage of the waste materials. To find the better combination mix, the GPC is categorized into four types as GPC-1, GPC-2, GPC-3 and GPC-4. In all the above combination of mixes fly ash is used as prime source material whereas QRD and RCA are replaced with different combinations. Thus this paper, particularly focuses on the effect of replacement of waste materials in combination of different mixes such as FA+CA, QRD+CA, FA+RCA, and QRD+RCA in GPC. The casted specimens are cured at ambient temperature and after three days of rest period, the casted specimens are tested to determine its mechanical strength properties using standard methodology.

Keywords* : FA-Fine Aggregate, CA-Coarse Aggregate, QRD-Quarry Rock Dust, RCA-Recycled Coarse Aggregate, GPC-Geo Polymer Concrete.

I. INTRODUCTION

Geopolymer was the name given by Davidovits [3] to materials which are characterized by chains or networks or inorganic molecules. GPC is studied extensively and it is a greener substitute for Ordinary Portland Cement Concrete in the concrete industry.

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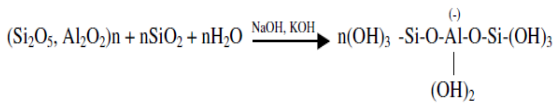
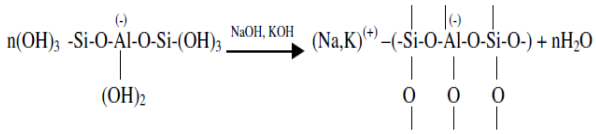
The main constituents of geopolymer sources of silicon and aluminium are provided by thermally activated natural materials (eg. kaolinite) or industrial by products (flyash or slag) and an alkaline activating solution the combination of NaOH and Na_2SiO_3 which polymerizes these source materials into molecular chains and networks to promote hardened binder.[4]

POLYMERISATION PROCESS

The schematic formation of geopolymer material can be shown as described by the following equations .[5]





II. MATERIAL PROPERTIES

A.LOW CALCIUM FLYASH

Mortar specimens made up of high alkali content geopolymer performed better than those manufactured with lower alkali content.[6] More compressive strength was obtained when class C flyash (CFA) was activated with the mixed alkali activator (sodium hydroxide and sodium silicate solution or potassium hydroxide and potassium silicate solution)[7]

Table-1: Properties of flyash

Sl. No.	*Property*	*Test Results*
1	Fineness	8%
2	Initial Setting Time	130 mins
3	Specific Gravity	3.16

B.QUARRY ROCK DUST

Quarry rock dust is the by-product which is formed during the processing of the granite stones which are broken down into coarse aggregates of different sizes, the powder content left over during the breaking of stones.[9]

Table-2: Properties of Quarry Rock Dust

Sl. No.	*Property*	*Test Results*
1	Specific Gravity	2.64
2	Fineness Modulus	2.86
3	Bulking of Sand	22%

C.FINE AGGREGATE

The fine aggregate shall consists of clean natural sand or crushed stone or a combination of both and shall confirm to IS: 383-1970. Fine aggregate shall be free from particles such as clay, shale, loam, cemented particles, mica, organic and other foreign matters. The test procedures for the determination of the physical properties, shall be in accordance with IS: 2386-1963 (Part1-8).

Table-3:Properties of Fine Aggregate

Sl. No.	Property	Test Results
1	Specific Gravity	2.6
2	Fineness Modulus	3.0
3	Bulking of Sand	20%

D.COARSE AGGREGATE

The coarse aggregate shall consists of clean, hard, dense, non-porous and durable pieces of crushed stone or crushed gravel, pieces of disintegrated stones, soft, flaky, elongated, very angular. The coarse aggregate shall confirm to IS: 383-1970. The test procedures for the determination of the physical properties, shall be in accordance with IS: 2386-1963.Coarse aggregate sizes of 20 mm and 12.5 mm shall be used in suitable proportions to satisfy the grading requirements for IS 20mm size.

Table-4: Properties of Coarse Aggregate

SI. No	*Property*	*Test Results*
1	Specific Gravity	2.75
2	Water Absorption	0.5%
3	Fineness Modulus	7.3
4	Crushing Strength	2.57 Mpa
5	Impact Value	7.2%

E.RECYCLED COARSE AGGREGATE

Recycled coarse aggregates are comprised of crushed, graded, inorganic particles processed from the materials that have been used in the constructions and demolition debris. Recycled coarse aggregate under the application of high strength structural concrete will give better understanding of the properties of concrete.[10]

Table-5: Properties of Recycled Coarse Aggregate

SI. No	*Property*	*Test Results*
1	Specific Gravity	2.76
2	Water Absorption	0.6%
3	Fineness Modulus	6.32
4	Crushing Strength	2.4Mpa
5	Impact Value	5.6%

F. ALKALINE ACTIVATOR

The alkaline activator shall be a combination of sodium or potassium hydroxide and sodium or potassium silicate.[11] Commercially available sodium silicate solution with a silicate modulus of 2.0 and bulk density of 1390 kg/cu.m and an analytical grade sodium hydroxide in pellet form from Nila Scientifics with 98% purity is used to adjust the activating solution.

III. MIX DESIGN PARAMETERS

The following parameters have been considered for evaluating the different mix proportions of GPC with various ingredients.[12]

i) Ratio of Source material to alkaline activator solution = 0.47

ii) Ratio of sodium hydroxide to sodium silicate = 2.5

iii) Concentration of NaOH = 16M

iv) Ambient Curing = 27°C

v) Extra water = 5% by volume of mass for GPC-1 and GPC-2 mixes.

vi) Extra water = 10% by volume of mass for GPC-3 and GPC-4 mixes.

PARAMETERS OF STUDY

The following parameters are considered in this experimental investigation:

(a) Different combinations of GPC mixes are considered :

i) Mix 1-(Combination of fine aggregate + coarse aggregate)

ii) Mix 2-(Combination of quarry rock dust + coarse aggregate)

iii) Mix 3-(Combination of fine aggregate + recycled coarse aggregate)

iv) Mix4-(Combination of quarry rock dust + recycled coarse aggregate)

(b) Rest Period: 3 Days

(c) Curing temperature: Ambient curing at room temperature (27°C)

(d) Age of concrete at the time of testing after rest period: 3days, 7 days, and 28 days.

The mix proportion of all GPC mixes and alkaline activator solution

Table -6: Mix Proportion of GPC mixes

GPC-1(kg/m³)			GPC-2(kg/m³)		
Flyash	FA	CA	Flyash	QRD	CA
550	568.81	1033.21	550	586.30	1033.21
1	1.03	1.87	1	1.06	1.87

GPC-3(kg/m³)			GPC-4(kg/m³)		
Flyash	FA	RCA	Flyash	QRD	RCA
550	568.81	972.03	550	586.30	972.03
1	1.03	1.76	1	1.06	1.76

Table-7: Mix Proportion of alkaline activator solution

Mix	NaOH kg/m³	Na_2SiO_3 kg/m³	Extra Water kg/m³
GPC1	42.17	239.64	27.50
GPC2	42.17	239.64	27.50
GPC3	42.17	239.64	55.00
GPC4	42.17	239.64	55.00

IV. EXPERIMENTAL SETUP

A. COMPRESSIVE STRENGTH TEST

i) The compressive strength was evaluated as per the test procedure given in Indian Standard IS 516.

ii) The compression test was carried out on specimens of metal moulds of cube with size 15 x15x15 cm.

iii) In assembling the mould for use, the joints between the sections of the mould were thinly coated with mould oil.

iv) All the mixes were compacted by layers using tamping rod with 25 blows for each layer.

v) Then after casting, the specimens were kept under rest period for three days and demoulded and left at ambient temperature for curing.

vi) Then the test specimens were placed between the upper and lower jaws of the compression testing machine and the machine was switched on.

vii) For the determination of compressive strength, all the cubes were subjected to compressive load in a digital Compression Testing Machine (CTM) of 2000KN capacity.

$$f_c = P/A$$

Where,

f_c = Compressive Strength, N/mm^2

P = maximum load applied to the specimen, (N)

A =cross-section area of the specimen ,(mm^2)

B. SPLIT TENSILE STRENGTH TEST

i) The split tensile strength was calculated as per IS 516. All the GeoPolymer Concrete specimens were casted using cylinders of 150mm diameter and 300mm height and demoulded after three days rest period.

ii) After curing, the specimens were placed in the machine in a horizontal manner in between the two parallel steel strips one at the top and another at the bottom such that the load shall be applied along the length.

iii) The load was applied without shock and increased continuously at a nominal rate within the range of 1.2 to 2.4N/mm^2/min until the specimens get failed.

iv) The figure 2 indicates the split tensile strength set up. The load at which the specimen got failed was noted and the strength was calculated using

$$ft = 2P/\Pi\, DL$$

where,

ft = Split tensile strength ,N/mm^2

P = maximum load applied to the specimen, (N)

D = diameter of the specimen,(m)

L= Length of the specimen,(m)

C. FLEXURAL STRENGTH TEST

i) The GPC mix was filled in layers and compacted using tamping rod.

ii) Then after the rest period of three days the specimens were demoulded and the specimens were placed in the machine in such a manner that the load was applied to the upper most surface by two point bending in UTM of 4000KN capacity.

iii) The axis of the specimen was carefully aligned with the axis of the loading device.

iv) The load was applied without shock and increasing continuously at a rate of 1800N/min.

v) The figure 3 indicates the flexural strength test set up. The load was increased until the specimen get failed, and the maximum load applied to the specimen during the test was recorded.

The flexural strength of the specimen was calculated using the equation

$$F_R = PL/BD^2$$

where,

fr = flexural strength, N/mm^2

P = maximum load applied to the specimen, (N)

L = Supported length of the specimen,(m)

B = width of the specimen,(m)

D = depth of the specimen,(m)

V. RESULTS AND DISCUSSION

A. COMPRESSIVE STRENGTH

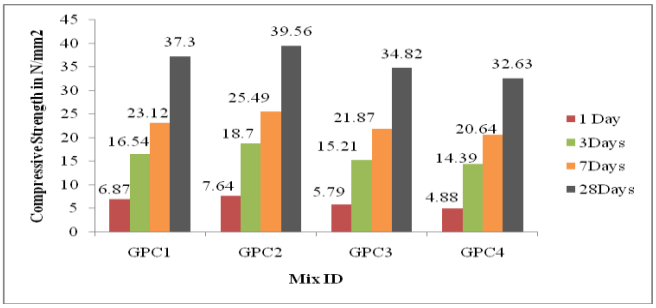


Fig. 1. Comparison of compressive strength of various mixes

The fig. 1 indicates the comparison of compressive strength of various mixes. The compressive strength depends upon the density of the concrete. When the density increases, the strength also increases.[14] Thus GPC mix 2 with QRD+CA results in good compressive strength compared to other mixes. At 3 days, the strength of GPC2 increases by 10.07%, 24.21%,and 36.12% compared to GPC1,GPC3, and GPC4. At 7 days, the strength of GPC2 increases by 11.55%,18.66%, and 23.04% compared to GPC1,GPC3,and GPC4 respectively. The more amount of silica present in quarry rock dust enhances the polymerization process with the source material fly ash which resulted in increase percentage of strengths due to the formation of more Si-O-Al bonds. At 28 days, the strength of mix GPC2 increases by 5.71%, 11.98% and 17.51% compared to other mixes GPC1,GPC3 and GPC4 respectively.All the compressive strength results are tabulated in table.8

Table-8:Compressive Strength of all GPC mixes

Mix	3 days (N/mm^2)	7 days (N/mm^2)	28 days (N/mm^2)
GPC 1	16.54	23.12	37.3
GPC 2	18.70	25.49	39.56
GPC 3	15.21	21.87	34.82
GPC 4	14.39	20.64	32.63

The compressive strengths of GPC mix 3 and mix 4 with the combination of FA+RCA and QRD+RCA were found to be less than other combinations. Due to absorption of water by recycled coarse aggregate, inherent the process of polymerization by reducing the amount of water in concrete matrix.[8] Since, the initial stage of polymerization requires more water to dissolve alumino-silicate atoms from the source material through the action of hydroxide ions in to a strong alkali solution.[12] Thus combination of quarry rock dust with recycled coarse aggregate results in reduced strength of concrete due to lack of water in concrete.

B. SPLIT TENSILE STRENGTH

The fig. 2 shows that split tensile strength of mix GPC2 with the combination of QRD+CA shows better results compared to all other GPC mixes. The formation of more Si-O-Al bonds in mix GPC2 increases the strength of the mix. At 3 days, the strength of GPC2 increases by 10.44%, 2.98%, and 9.45% compared to GPC1,GPC3 and GPC4. All GPC specimens gained their strength at ambient curing of temperature with rest period of three days.[15] The combination mix of quarry rock dust and coarse aggregate gave better results compared to the combinations of quarry rock dust and recycled coarse aggregate due to the increase in ratio of Si/Al ratio in quarry rock dust. All values of split tensile strength are tabulated in table.9.

Table-9: Split Tensile Strength of all GPC mixes

Mix	3 days (N/mm^2)	7 days (N/mm^2)	28 days (N/mm^2)
GPC 1	1.8	2.46	3.13
GPC 2	2.01	2.74	3.46
GPC 3	1.95	2.32	2.84
GPC 4	1.82	2.13	2.62

At 7 days, the strength of GPC2 increases by 10.21%, 15.32%,and 22.26% compared to GPC1,GPC3,and GPC4. The split tensile strength of mix GPC2 at 28 days increases by 9.53%, 17.91%, and 24.27% compared to other mixes GPC1, GPC3 and GPC4 respectively. Thus incorporating optimum percentage of recycled coarse aggregate shows less strength whereas addition of optimum percentage of quarry rock dust showed enhanced strength in GPC.

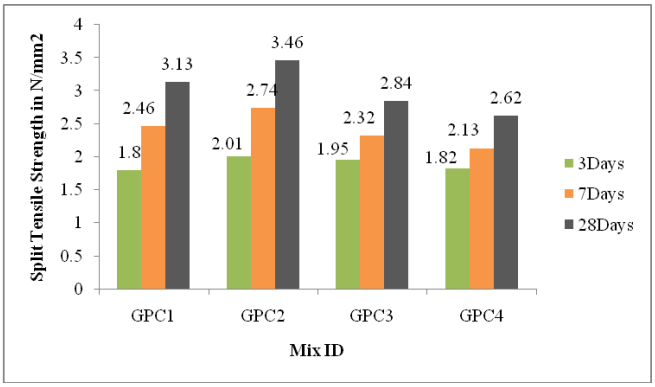


Fig. 2. Comparison of split tensile strength of various mixes

C. FLEXURAL STRENGTH

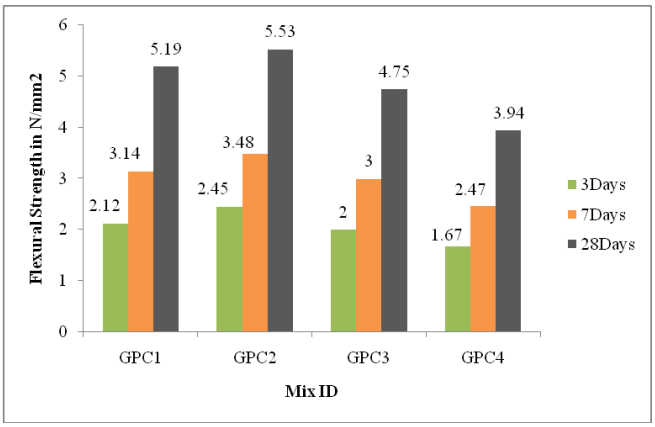


Fig. 3. Comparison of Flexural strength of various mixes

The fig. 3 shows that flexural strength behavior of GPC mixes. At 3 days the strength of mix GPC2 increases by 13.46%,18.36%,and 31.83% compared with GPC1,GPC3,and GPC4.At 7 days, the strength of GPC2 increases by 9.77%,13.79%,and 29.02% compared with GPC1, GPC3, and GPC4.All the values are shown in table.10

Table-10: Flexural Strength of all GPC mixes

Mix	3 days (N/mm^2)	7 days (N/mm^2)	28 days (N/mm^2)
GPC 1	2.12	3.14	5.19
GPC 2	2.45	3.48	5.53
GPC 3	2.00	3.00	4.75
GPC 4	1.67	2.47	3.94

Also performed well with the formation of more number of three dimensional links compared to all other combinations of GPC mixes. The high 16M concentration of sodium hydroxide reacts with the silica and alumina present in quarry rock dust to form aluminates and silicates which results in the formation of more ring structures, results in gain of higher strength. The maximum strength in the optimum mix with recycled coarse aggregate showed less percentage compared to all other mixes, due to less strength carrying capacity of recycled coarse aggregate.[16] The flexural strength at 28 days of mix GPC2 increases by 6.14%, 14.10%, and 28.75% compared to other mixes GPC1, GPC3, and GPC4 respectively.

Thus the combination of optimum mix of two materials namely QRD+RCA showed lesser strength. But the optimum mix with QRD+CA showed better results compared to other mixes.

D. PERCENTAGE GAIN IN STRENGTH

The fig. 4 shows percentage gain in strength of compressive strength, split tensile strength and flexural strength of mix GPC2 at 28 days. The gain in compressive strength of mix GPC2 compared to mix GPC1, GPC3 and GPC4 was 5.71%, 11.98%, and 17.51% respectively. The gain in percentage of split tensile strength of mix GPC2 compared to GPC1, GPC3, and GPC4 was 9.53%, 17.91%, and 24.27% and flexural strength of mix GPC2 increased by 6.14%, 14.10%, and 28.75%.

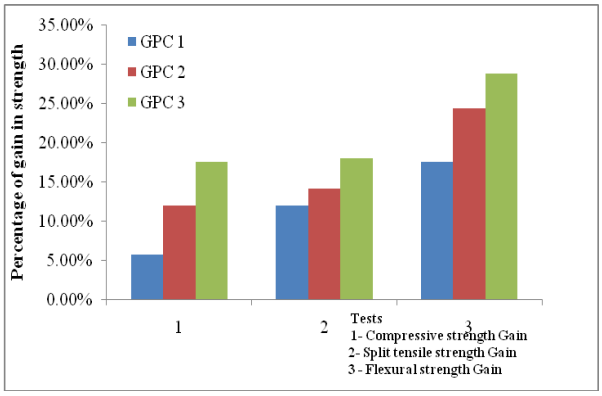


Fig. 4. Percentage gain in strength

VI. CONCLUSION

- From the test results it was found that the Combination of (QRD + CA) gave better compressive, tensile and flexural strength properties when compared to all other combination of GPC mixes such as (*FA+CA, FA+RCA, and QRD+RCA)*
- Compared to all GPC mixes, the percentage gain of compressive strength of GPC2 (QRD+CA) at 28 days increases by 5.71%, 11.98%, and 17.51% with all other mixes such as GPC1, GPC3, and GPC4 respectively.
- The percentage gain in strength at 28 days, the split tensile strength of mix GPC 2 (QRD+CA) increases by 9.53% with GPC1, 17.91% with GPC3, and 24.27% with GPC4.
- At 28 days, the percentage gain in strength of flexural strength of mix GPC2 (QRD+CA) increases by 6.14% with mix GPC1, 14.10% with GPC3 and 28.75% with GPC4.

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