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Strength and Durability of Self-Curing Concrete using Recycled Aggregate

Nagasree D[1], KL Radhika[2]
[1, 2] *Department of Civil Engineering, Osmania University*

Abstract:* The strength and durability of the concrete is dependent on curing. Self curing concrete can be used where curing is a constraint because of inadequacy of water, fluoride content in water which affects concrete characteristics and where structures cannot be accessed for curing. Poly Ethylene Glycol (PEG), Poly vinyl Alcohol (PVA), paraffin wax, acrylic acid is some of the commonly available hydrophilic materials in market. As aggregate represents about 70-80% of concrete components so it will be beneficial to recycle the aggregate for construction works and also to solve the environmental problems. To minimize the problem of excess of waste material it is a good step to utilize the recycled aggregates provides that the desired final product will meet the standards. Current practice assesses the quality of concrete based primarily on strength. It has been suggested that the quality of concrete should be characterized not only by strength but also its durability characteristics. In the present investigation the individual effect of curing agents like PEG 600 and PVA on strength and durability properties of concrete with varying dosages of 0.5%, 1%, 2% was investigated for M30 grade of concrete using recycled aggregate. Compressive strength, flexural strength, tensile strength and sorpitivity, acid attack and permeability were evaluated to determine the strength and durability properties of hardened concrete. It was found that PEG600 and PVA could help in gaining the strength of conventional curing. The results indicate that PEG600 of dosage of 2% and PVA of dosage of 1% was optimum by giving strength on par with conventional concrete. The results indicate that self-curing concrete performs similar to the conventional concrete in all aspects of durability.

***Keywords*: Recycled Aggregate, Poly ethylene glycol (PEG-600), Poly vinyl alcohol (PVA), mechanical properties, Durability properties**

I. INTRODUCTION

Concrete like other engineering materials needs to be designed for properties like strength, durability, workability. A durable concrete is one that performs satisfactorily under the anticipated exposure condition during its designed service life. With advent of new generation admixtures, it is possible to achieve higher grades of concrete with high workability levels economically. Depending upon the nature of work the cement, fine aggregate, coarse aggregate and water are mixed in specific proportions to produce plain concrete. Traditional concrete needs congenial atmosphere by providing moisture for a minimum period of 28 days for good hydration and to attain desired strength. Proper curing of concrete structures is important to meet performance and durability requirements. In conventional curing this is achieved by external curing applied after mixing, placing and finishing. Any laxity in curing will badly affect the strength and durability of concrete. Self-curing or internal curing of concrete is the technique that can be used to provide additional moisture in concrete for more effective hydration of cement and reduce self-desiccation. Internal curing is a method to provide the water to hydrate all the cement, accomplishing what the mixing water alone cannot do. A concrete can be made to self-cure by adding curing admixtures or by the application of curing compounds. The use of self-curing admixtures is very important from the point of view that water resources are getting valuable every day. Utilizing recycled aggregate is certainly an important step towards sustainable development in the concrete industry and management of construction waste. Recycled aggregate (RA) is a viable alternative to natural aggregate, which helps in the preservation of the environment. One of the critical parameters that affect the use of recycled aggregate is variability of the aggregate properties. 100% replacement of natural aggregates by recycled coarse aggregates would reduce the structural performance characteristics. Use of recycled aggregate up to 30% does not affect the functional requirements of the structure as per the findings of the test results of previous investigations.

II. LITERATURE REVIEW

Use of superabsorbent polymer (SAP) is a new concept for the prevention of self-desiccation in hardening cement based materials [9, 10]. SAP particles are used as a concrete admixture which absorbs free water in concrete and form macro inclusions [11]. The formed water-filled macro pore inclusions will enable to provide the moisture required in fresh concrete. This formation will actively aid in controlling the self-dehydration of concrete. Some studies concentrated on cracking and shrinkage properties on self-curing concrete when SAP is used as the self-curing agent [12, 13]. These studies conclude that the compressive strength of concrete decreases with higher content of SAP. Liang and Sun carried out studies on internal curing composition of concrete when glycol and wax is added to concrete [14]. They observed that the addition of proper composition glycol and wax makes the internal curing of concrete in many aspects equal to or superior to traditional curing techniques. The study states that a paraffin wax, polyethylene glycol (PEG) and methoxypolyethylene glycol (MPEG) of molecular weight 200 to 10000 can be used as a preferred composition for internal curing. The study also concludes that PEG of molecular weight 200-800 is the most preferred for self-curing agents. Other studies argue that SC is provided to absorb moisture from surrounding air there by achieving a superior hydration of cement in concrete [4, 5, 15]. In their study, self-curing agent about 0.1-5% weight of cement of the concrete was added to the concrete during mixing. The function of the SC agent is to absorb moisture from air and then release it to concrete. A different study used polymeric glycol (PG) as a self-curing agent in concrete. PG is a water soluble agent which has water retention capacity [3]. The amount of water retention was calculated by taking concrete weight measurements and internal humidity measurements. The amount of retained water in concrete at different ages was measured to evaluate the hydration. Measurements on absorption percentage, permeable voids percentage, water absorptivity and permeability were used to calculate water transportation capacity. A recent study concentrated on the performance of concrete made with commercially produced coarse recycled aggregate [16]. Commercially graded unwashed aggregates were used with fine sand to create the aggregate mixture. Several properties such as workability, compressive strength, split tensile strength, drying shrinkage, abrasion resistance, and water absorption etc. were critically compared in the analysis. The results indicated that there is no significant difference in compressive and tensile strength at a 5% significant level. Another study concentrated on a production method and a mix design for concrete with recycled coarse aggregate. [20]. Another important aspect in the study was the consideration of economic factor associated with recycled aggregate production. The results of the study conclude that recycled aggregate can be produced by a simple assembly of equipment, as the replacement ratio increases the performance such as compressive strength decreases. In contrast, some studies point out importance of analysis of durability of recycled concrete [19, 21]. These studies used durability indices to evaluate the durability considerations of recycled concrete.

III.METHODOLOGY

A. The materials used

1) 53 Grade ordinary portland cement
2) Fine aggregate
3) Coarse aggregate (conventional and recycled)
4) Polyethylene glycol-600
5) Polyvinyl Alcohol
6) Water

The cement used in the investigation is 53 grade ordinary Portland cement confirming to IS12269:2013. The fine aggregate conforming to zone III according to IS 383:1970 was used. The specific gravity of the sand used was 2.63.
The coarse aggregate conforming to IS 383:1970 (Table II)
was used. Maximum coarse aggregate size used 20 mm. Polyethylene Glycol (PEG) which is a condensation polymer of ethylene oxide and water was used as a SC agent. Polyvinyl alcohol is produced commercially from polyvinyl acetate, usually by a continuous process. The acetate groups are hydrolyzed by ester interchange with methanol in the presence of anhydrous sodium methylate or aqueous sodium hydroxide. Polyvinyl alcohol is an odorless and tasteless, translucent, white or cream coloured granular powder. Polyvinyl alcohol contains two OH groups. An interesting feature of PEG-600 & PVA is that it is water-soluble and helps to retain water. Specifications of PEG-600 & PVA are listed in Table II.

TABLE I
PROPERTIES OF NA AND RCA

Property	Bulk Density	Specific gravity	Fineness modulus
NA	1.547	2.625	7.73
RCA	1.417 gm/cc	2.46	7.36

TABLE II
SPECIFICATIONS OF PEG AND PVA

Property	Molecular Weight	Appearence	Specific gravity	PH
PEG	600	Clear liquid	1.12-1.13	5-7
PVA	14000	translucent, white or cream colored granular powder	1.19 - 1.31	5- 6.5

Mix design of concrete is done as per IS:10262-2009 for M30 grade concrete. Mix proportion by weight is 1:2.7:3.8.

B. Casting Programme

Casting programme consists of preparation of moulds (as per IS 10086:1982), preparation of materials, weighing of materials and casting of cubes, cylinders, beams. Mixing, compacting and curing of concrete are done according to IS 516:1959. The cubes which are intended for self-curing are kept in in-door/shade at room temperature. Materials required for the mix is as shown below in Table III.

C. Experimental Investigations

The casted specimens were then tested on Universal Testing Machine (UTM) with a weight of 3000 kN as per IS 516:1959 after 28 days of curing. Both the specimen and the bearing surface of the UTM were cleaned from dirt to obtain a proper bond between the two surfaces when load is applied. The specimen is then placed in UTM in such way that the smoother sides of the cube facing the load applying axis. The axis of the specimen was carefully aligned to make it coincide with the centre of loading frame. The load was increased with a constant rate until the load resistance capacity of the specimen is lost completely. The maximum load the specimen can withstand is recorded. This process is repeated for all the mix design specimens. Compression testing machine of capacity 3000 kN was used to test cylindrical specimens. The
preparation process for the cylindrical specimens is similar to the cubical specimens. The maximum load in which the specimen can sustain is then recorded. The beam specimens were also prepared for testing according to the procedure mentioned before. Two-point loading was used to generate bending moment on the specimen. Both the loads were increased at a constant rate until the specimen is no longer able to sustain any more loading. The maximum load applied on the specimen is recorded. The maximum load the cube, cylinder and the beam can withstand are then utilised for calculation of average compressive strength, Split tensile strength and flexural strength respectively.

Sorptivity test is a very simple technique that measures the capillary suction of concrete when it comes in contact with water. The Sorptivity test was performed in accordance with the ASTM C 1585 [11]. This test is used to determine the rate of absorption (Sorptivity) of water by measuring the increase in the mass of a specimen resulting from absorption of water as a function of time when only one surface of the specimen is exposed to water ingress of unsaturated concrete by capillary suction during initial contact with water. The rate of sorption is the slope of the best-fit line to the plot of absorption against square root of time. Sorptivity specimens were prepared by cutting a disc of 100 ± 6mm diameter with 50±3mm length. The cumulative water absorption (per unit area of the inflow surface) increases as the square root of elapsed time (t).

Mass gain due to sorption will be measured at definite intervals for the first six hours.

$S = (Q/A)\sqrt{t}$

Where Q = water absorbed in cm3

A = surface area in contact with water in cm2

t = time in sec

S = sorpitivity in cm/√s

Concrete is susceptible to attack by sulfuric acid produced from either sewage or sulfur dioxide present in the atmosphere of industrial cities. The hardened cement paste binder in concrete is alkaline, and therefore no Portland cement concrete can be considered acid resistant. However, it is possible to produce a concrete that is adequately durable for many common circumstances by giving attention to low permeability and good curing. In these circumstances, acid attack is only considered significant if the pH of the aggressive medium is less than about 6.

The chemical resistance of the concrete is studied through chemical attack by immersing concrete blocks in Sulphuric acid ($H2SO4$) solution. After 28 days of self-curing immerse the specimens in 5% sulphuric acid solution. After removing the specimens from the solution, clean the surfaces with a soft nylon wire brush under the running tap water to remove weak products and loose material from the surface. Then allow the specimens to surface dry and measure the masses and determine the compressive strength.In acid attack test weight loss, reduction compressive strength is determined to evaluate the extent of concrete deterioration due to sulphuric acid attack.

One method of estimating the durability of a porous material is by measuring the rate at which a fluid, gas or liquid permeates through the material under a given head of pressure (Permeability). Therefore, the measurements of the permeability of concrete were used as an indication of durability. The more quickly a fluid moves through the material (higher permeability), the lower anticipated durability. Similarly, if a fluid moves through the material at a very slow rate (low permeability), a high durability would be expected. Permeability is the key to all durability problems. Permeability of concrete can be measured by the automatic concrete water permeability device on cylinders of dimensions (150 × 150 mm) as shown in Fig 4. The sides of the specimen are sealed with epoxy and water under pressure is applied to the top surface only. The device applies a hydrostatic water pressure of 10kg/cm². The water permeated through specimens is directly collected and measured in a graduated cylinder. By knowing the hydrostatic pressure, duration, specimen dimensions, and the permeated amount of water, it is possible to determine the permeability coefficient in cm/sec by applying Darcy's law:

$$K = \frac{Q \times H}{A \times T \times P}$$

Where: Q = permeated water, cm 3
H = height of the specimen, cm
A = surface area of the specimen, cm2
T = test time, sec P = water head, cm

IV. EXPERIMENTAL PROGRAMME

The experimental program is designed to investigate the strength of SC M30 concrete in terms of compressive strength, split tensile strength, flexure strength using Polyethylene glycol and Polyvinyl alcohol (SC agent) with 30% replacement of Natural Aggregate (NA) by Recycled Coarse Aggregate (RCA).

The problem consists of casting and testing of Specimens. The specimen of standard cubes (150mmx150mmx150mm), Cylinders (150mmx300mm height) (100mx50mm height) & (100mmx150mm height), Prisms (100mmx100mmx500mm) were casted for M30 standard grade concrete for two different self curing agents viz., polyethylene glycol and polyvinyl alcohol with varying dosages viz., 0.5%, 1%, 2% using natural aggregate and recycled coarse aggregate .In the investigation as per the literature review the maximum dosage of self curing agent is restricted to 2% and minimum dosage is of 0.5%. 100% replacement of natural aggregates by recycled coarse aggregates would reduce the structural performance characteristics. Use of recycled aggregate up to 30% does not affect the functional requirements of the structure as per the findings of the test results of previous investigations. Hence 30% of natural aggregate is replaced with recycled aggregate.

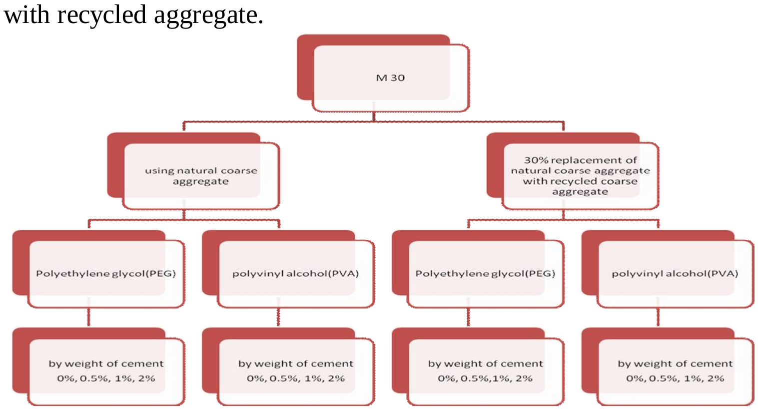

FIG I: EXPERIMENTAL PROGRAMME

V. RESULTS AND DISCUSSION

TABLE IV
STRENGTH PROPERTIES

Mix M30	Avg. compressive strength (N/mm2)		Split tensile strength (N/mm2)		Flexural strength (N/mm2)	
	7 days	28 days	7 days	28 days	7 days	28 days
NC-NA-0	28.95	38.60	1.57	2.35	4.50	5.00
NC- RCA-0	28.05	36.50	1.69	1.43	2.17	3.80
SC- RCA- PEG-0.5	25.70	35.00	1.45	2.10	2.73	3.65
SC- RCA- PVA-0.5	26.00	34.00	1.49	2.20	3.47	5.19
SC- RCA- PEG-1	26.66	35.88	1.90	2.40	3.45	4.94
SC- RCA- PVA-1	26.22	35.00	1.83	2.45	3.69	5.51
SC- RCA- PEG-2	27.00	38.00	1.85	2.50	4.20	5.00
SC- RCA-PVA-2	25.50	35.00	1.53	2.25	3.97	4.97

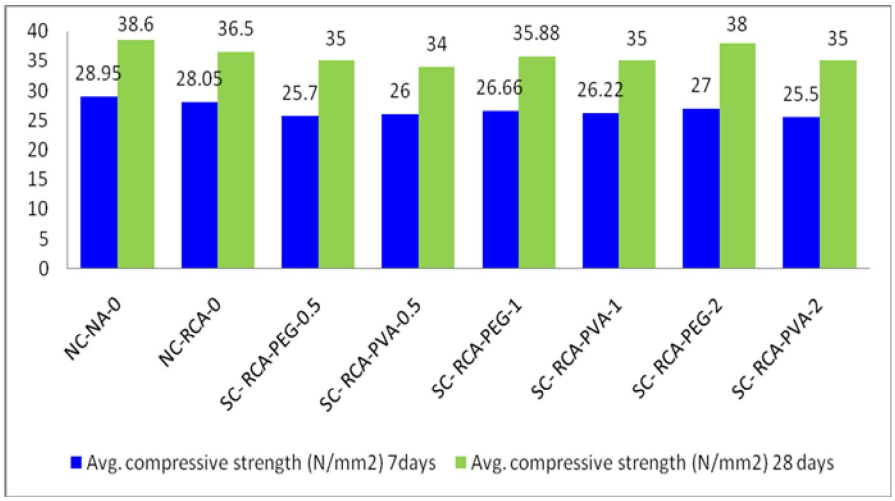

FIG II: COMPARISON OF COMPRESSIVE STRENGTH

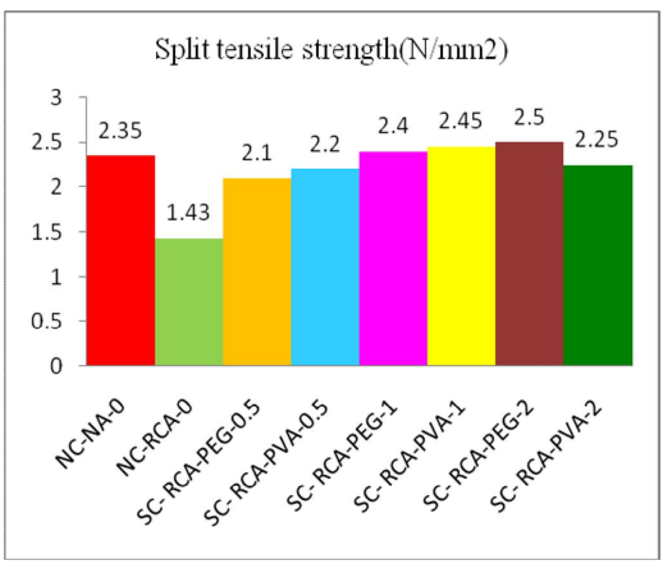

FIG III: COMPARISON OF SPLIT TENSILE STRENGTH

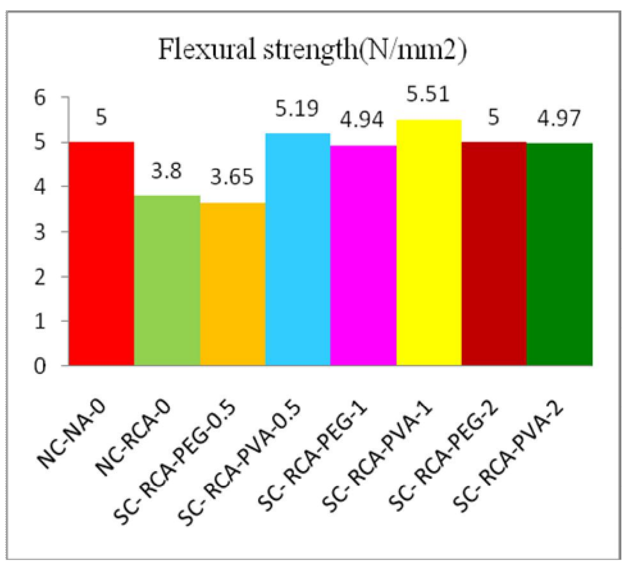

FIG IV: COMPARISON OF FLEXURAL STRENGTH

TABLE V
DURABILITY PROPERTIES

Mix M30	Percentage reduction of compressive strength due to acid attack	Sorpitivity I(mm x 10^{-3})	Permeability Cm/sec x 10^{-5}
NC-NA-0	5	0.146	2.60
NC-RCA-0	6	0.063	3.04
SC-RCA-PEG-0.5	5	0.112	3.04
SC-RCA-PVA-0.5	7.01	0.128	2.45
SC- RCA-PEG-1	4.50	0.098	2.55
SC- RCA-PVA-1	5.2	0.096	2.22
SC- RCA-PEG-2	4	0.091	2.06
SC- RCA-PVA-2	5.71	0.085	1.96

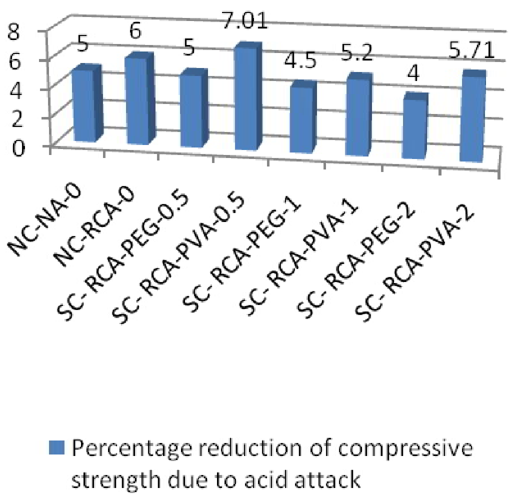

FIG V: ACID ATTACK

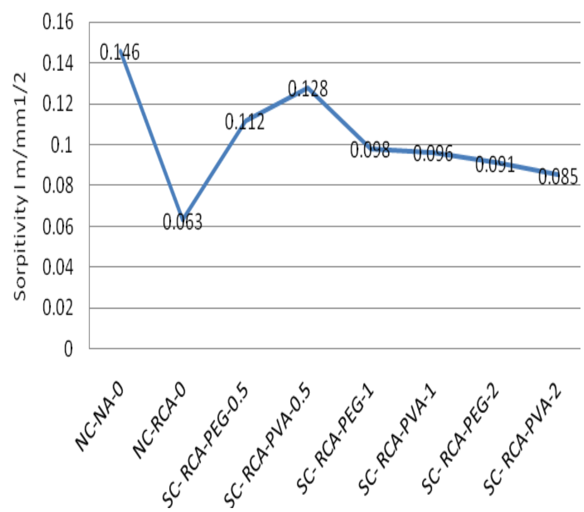

FIG VI: SORPITIVITY

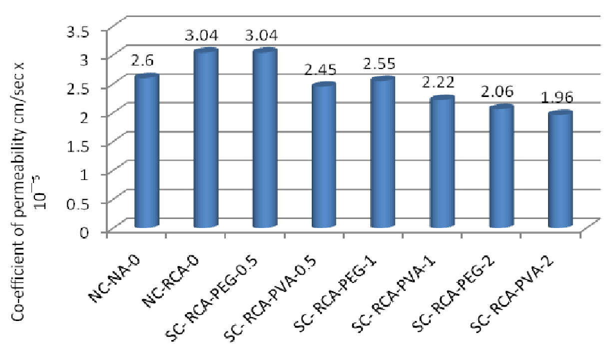

FIG VII: PERMEABILITY

VI. CONCLUSION

It can be seen that the minimum strength as per the codal provisions has been achieved by the specimens cured through curing compounds. Durability is not affected much by using chemical compounds for curing. Performance of both the curing compound was almost same for Self Curing Concrete. The optimum dosage of PEG600 for maximum strength was found to be 2% for M30 and The optimum dosage of PVA for maximum strength was found to be 1% for M30.

The use of self-curing agents increases the structural performance of samples with both aggregate types. This increase in normal aggregates is higher than that of recycled coarse aggregates. The amount of debris present in the recycled coarse aggregate sample is the major reason for this decrease of strength. This may also be due to the quality and properties of recycled aggregate and on the quantity and quality of cement mortar, which is attached to the grains of recycled aggregate, that is, on the quality of the original concrete by whose recycling the aggregate is produced.

VII. ACKNOWLEDGMENT

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