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Experimental Analysis of Concrete using Recycled Aggregates and Rochelle Salt

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***Abstract*—There is a phenomenal rise in constructional and demolition waste and disposal of waste material which is a matter of concern for environmentalists even today. Much research has been going on for the usage of waste produced due to the demolition of structures in concrete as recycled aggregates. Recycled aggregate has been used in several projects in numerous American, European, Russian, and Asian nations. However, structure health and strength also play an important role but using recycled aggregates reduces the mechanical properties of concrete. The addition of any type of chemical admixtures will lead to enhance the properties of recycled aggregate concrete. In this paper, recycled aggregates as partial replacement of natural aggregates and Rochelle salt as an admixture is used to observe whether the presence of sodium-potassium ions will affect the mechanical properties of concrete or not. The research work is generally concentrated on witnessing the effect of Rochelle salt on properties of recycled aggregate concrete such as workability, compressive, flexural, split tensile strength, abrasion resistance and effect of salt admixture on concrete. Different proportions of Rochelle salt and a fixed percentage of recycled aggregate will be used in concrete and desirable results will be obtained.**

***Keywords*—Recycled concrete aggregates, rochelle salt.**

I. INTRODUCTION

A. Structure of Concrete

In modern era widely used building material worldwide is concrete. It is combination of highly diverse material like cement, water, coarse aggregate and fine aggregate. In certain situations admixture, different type of fibres and many chemicals as required in its preparation for different applications. Once above mentioned materials combined together in a specified proportion then these ingredients form a fluid mass that is easily molded and transformed into any desired form. After proper curing it is converted to hard, dance, homogenous material referred as concrete. “Wood cannot be used for dam, steel for pavement construction, or bitumen to render building outline, however concrete can be used of the mentioned for each and several other purposes, rather than other building materials” as quoted by J.W. Kelly.

Physical properties are the resultant product of the material's internal structure. Thus, the material properties can be modified by making adjustments with the material's inner structure. The inner concrete structure is very complex. The aggregate phase, the cement matrix phase and the 2-transition phase are all three stages isolated with microscopic concrete structure. Physical properties such as unit weight, young modulus and rigidity arise from the aggregates phase. Hydrated cement phase and aggregate phase is interfacial region of transition phase, since it is concrete fragile zone and thus has greater effect on the mechanical behaviour of the concrete. The engineering properties characteristics of concrete are greatly impacted by the hardened cement paste (hcp). The hardened cement paste properties further depend upon micro-structure in which maximum part comprises of voids and solids. Major effect on concrete properties is due to presence of un-hydrated clinker particles, calcium aluminium sulphates, calcium hydroxide, air voids and capillary voids. There is variation of capillary voids from 10-50mm and air voids vary from 50-200 µm.

B. Structure of Recycled Aggregate Concrete

The concrete made with recycled aggregate usually has far more complicated form than natural aggregate concrete, mainly because of the presence of two dissimilar forms of interfacial transition zones within the arrangement of grains. There is formation of old and novel interfacial transition zones. Whereas the novel interfacial transition zone is situated between the recycled aggregate particles and new cement mortar. The old interfacial transition is positioned in the middle of primary grain and primary cement mortar which is entirely or partly attached to it whereas the new transition zone is situated between the new cement mortars and recycled aggregate grain. Moreover, complexity of recycled aggregate concrete is even more prominent when a mix is prepared by partially replacing natural aggregates with recycled aggregates. Then, there is formation of two interfacial transition zone between cement mortar and natural aggregates however, second interfacial transition zone between recycled aggregates and cement mortar. The arrangement of the interfacial transition zone has inferior density if the aggregate grain has surface layer of greater density. In fact, in the interfacial transition zone there is existence of more calcium hydroxide (Ca (OH) 2) crystals associated with the interfacial transition

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zone at the 3 proximity of natural non permeable aggregates, so that the water that collects in the surrounding area of grains do not immerse into the pore of aggregates, to same level which it would have immersed if the grain was more permeable. Denser interfacial transition zone indicates better bond among grain of aggregates and cement matrix, and lastly accomplish better mechanical properties.

C. Rochelle Salt

Rochelle salt is chemically also known as potassium sodium tartrate tetrahydrate (KNaC4H4O6•4H2O). Rochelle salt derives its name from a city in France, La Rochelle from where Pierre Seignette who invented the salt belongs. It is a colourless and neutral crystalline solid which has large piezoelectric effect. The mechanical deformation such as pressure, twisting and bending induces electric charge on its surface. One of the oldest most used piezoelectric transducers is Rochelle salt and it is green salt which has less or no harmful impact on the environment. Rochelle salt was first material which has ferroelectric phenomenon which was discovered by Valasek in 1921, and phrased it ferroelectric curie point. Discussing the ferroelectric properties of this is material is very important because the most riveting characteristics of Rochelle salt is that it demonstrates two different curie points, one at 24°C, known as the upper curie temperature, and other called as lower curie temperature at -18°C. Rochelle salt transducers have been used extensively in the recent times and voltage production up to 2V has been obtained. The piezoelectric development is the electro mechanics which focus attention on the relation of mechanical and electrical system in crystalline material. Mechanical stress such as compression and tension produce voltage in the material which is proportional to that stress. Electric charge which is obtained when pressure applied is called as direct effect.

The converse effect which is opposite of direct effect in which when material is exposed to an electric field, there is mechanical deformation in the crystal correspondent to the field. Structure should be stringent it must have proper arrangement to manage the actuators and sensors. Because of mechanical pressure, it yields surface charge. On the one hand, due to application of electric field shape deformation takes place in material. This extraordinary material has potential to empower the material to make practical and effective use as a sensor and actuator. Phenomenon in which a pair of equal and opposite electric charges is separated by a small distance (dipole) in solid crystals was generally the cause of piezoelectric effect. When mechanical load such as tension or compression is applied there is movement in the polarization of certain dipoles changes that generates electric charge on solid crystal. In case of piezoelectric effect of Rochelle salt, it was presumed that order and disorder of the oxygen cluster bind to salt is main reason of piezoelectricity nevertheless inelastic neutron scattering information has confirmed that any static displacement, initiate the exposure of dipoles in local structure components. Rochelle salt has tendency to absorb moisture and dissolve and cannot be stored in humid condition so its use has been forbidden. While alcohol mixing and heating can be done to make it less deliquescent but influence of this does not persist for a long time.

D. Recycled Aggregates

Recycled Aggregates which is easily available in huge amount, obtained from the demolition of old structures or from left-over concrete from new construction, creates a huge problem for disposal. The left-over concrete can then be use as Recycled Aggregates (RA) as a substitute for Natural Aggregates (NA) for construction. There is a lot of difference between RA and NA in their composition due to attached cement mortar content. Keeping in view the issue of disposing the demolished waste and lack of availability of natural aggregates, there has been an increasing demand of recycled aggregates (RA) for construction purposes. Furthermore, incorporation of RA as a partial or full replacement to natural aggregates (NA) affects the mechanical and durability properties of the concrete. Hence, globally, investigations have been going on using varied techniques with an objective to augment the performance of concrete made by integrating RA. By replacing some proportion of NA with RA there are lot of benefits such as savings in the limited landfill spaces and less depletion of natural resources.

Performance of RAC depends upon the source of RA, production process of RA and quantity of adhere mortar bind to the surface of aggregates. Concrete Compressive strength primarily depends on the RA, superior if quality of aggregates is used such as high crushing strength, using admixtures or other replacement in concrete then recycled aggregates has no or very less influence on properties of concrete

II. EXPERIMNETAL DETAILS

Experimental setup, investigational program and methodology for the assessment of harden properties of concrete like compressive strength, flexural strength and split tensile strength made with different proportion Rochelle salt as partial substitute of cement and recycled coarse aggregates as fractional replacement of natural aggregates.

A. Mix Design

A mix design of concrete was prepared as per the guidelines of IS 10262:2019. Grade of concrete was selected as M25 and slump was considered 75mm. Exposure condition were considered as moderate. Firstly, target strength was calculated by taking standard deviation of M25 from code. Water cement ratio is selected from the graphs of two different codes IS 456 2000 and IS 10262 2019. The chosen w/c ratio is checked and lower of ratio both is adopted. Maximum water content of concrete with aggregates of nominal size is confirmed. The adopted water content is then used for computing cement content. In the next step, quantity of coarse and fine aggregates were calculated and correction, were applied to calculate the quantities.

From the above steps, total volume of all the materials used in concrete mix was calculated. Concrete mix embedded with recycled coarse aggregates (30%) as partial replacement of natural coarse aggregates and Rochelle salt (0.45%, 0.55%, 0.75%, 1%, and 1.25%) as replacement of cement. All mix design has been codified as CM (control mix), RAC30 (30% recycled aggregates in concrete), R1 (recycled aggregates 30% and 0.45% Rochelle salt), R2 (recycled aggregates 30% and 0.55% Rochelle salt), R3 (recycled aggregates 30% and 0.75% Rochelle salt), R4 (recycled aggregates 30% and 1% Rochelle salt), R5 (recycled aggregates 30% and 1.25% Rochelle salt).

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B. Preparation of Samples

For casting samples steel moulds were used. Before pouring concrete moulds were cleaned properly and then oiling was done before concrete mixing. Moulds were appropriately fixed to proper dimension before casting of concrete.

a. Compressive Strength: To perform compression, test cubical specimens of size 150mm x 150mm x 150mm were casted.
b. Splitting Tensile Strength: Cylindrical specimens having height of 300mm and diameter of 150mm were utilized for performing split tensile test of concrete.
c. Flexural Strength Test: Rectangular specimens of size 100mm x 100mm X 500mm were casted for flexural strength test of concrete.
d. Abrasion Resistance: Cubes of size 70mm x 70mm x 70mm were casted to perform this test.

III. RESULTS AND DISCUSSION

Various experimental investigation test results are described and discussed. In the first part physical properties of Ordinary Portland cement (OPC), coarse aggregates, fine aggregates, recycled aggregates and Rochelle salt are discussed. For OPC, physical testing includes specific gravity, initial setting time, final setting time and compressive strength of cement mortar cubes. For fine aggregates sieve analysis, water absorption, specific gravity and fineness modulus are used. For coarse aggregates water absorption, specific gravity and fineness modulus are determined. For recycled aggregates various test such as water absorption and specific gravity are evaluated. Moreover, for Rochelle salt specific gravity, odour, solubility test are performed.

A. Rochelle Salt

Physical properties of raw Rochelle salt were revealed in table I.

TABLE I: PHYSICAL PROPERTIES OF ROCHELLE SALT.

S. No	Physical Requirement	Test Values
1.	Appearance	Colorless Crystals
2.	Melting point	73°C
3.	Solubility in water	66g/100ml
4.	Specific Gravity	2.0
5.	Odor	Odorless

B. Cement

The different physical properties of cement were mentioned in table II. The test results of material were as per IS: 8112-1989.

TABLE II: LIMITING VALUES OF PROPERTIES OF CEMENT AS PER IS

S. No	Physical Requirement	Test Results	Specification according IS: 8112-1989
1.	Specific Gravity	3.13	-
2.	Standard Consistency	28	-
3.	Initial Setting Time	175	>30
4.	Final Setting Time	250	<600
5.	3 day Compressive Strength (MPA)	25.1	23
6.	7 day Compressive Strength (MPA)	34.6	33
7.	28 day Compressive Strength (MPA)	45.2	43

C. Coarse Aggregates and Recycled Aggregates

The coarse aggregates 10 mm and 20 mm were used in combination in concrete mix. Coarse aggregates were locally bought and confirm BIS 383:1970 specifications whereas recycled aggregates were prepared in lab. A variety of physical tests were performed on coarse and recycled aggregates, results are shown in table III and fig 1.

TABLE III: PHYSICAL PROPERTIES OF COARSE AGGREGATES

S. No	Physical Requirement	Natural Aggregates Test Results	Recycled Aggregates Test Results
1.	Specific Gravity	2.65	2.22
2.	Water Absorption (%)	1	5.4
3.	Shape	Angular	Angular
4.	Moisture Content	Nil	Nil
5.	Fineness modulus	7.4	-

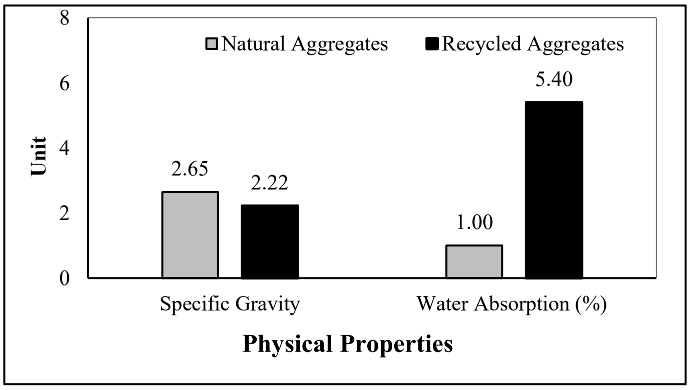

Fig 1: Comparison of physical properties of natural and recycled aggregates.

D. Specific Gravity

The RCA specific gravity was 2.22 which was less than natural aggregates 2.65 but results were satisfying. If specific gravity is less than 2.2, it might cause honeycombing, segregation and also efficiency of concrete may decreased.

E. Water Absorption

The RCA from demolished concrete contain of crumpled stone aggregate with mortar attached to it, the water absorption of RA was 5.4% which is relatively higher than that of the natural aggregates having water absorption of 1%. Therefore, the water absorption outcomes are acceptable.

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F. Workability

Slump test was performed on freshly prepared concrete for workability, to study the effect of rochelle salt and recycled aggregates on concrete workability and results shows decrement in workability of concrete. It can be realized that slump of concrete decreases with addition of recycled aggregates. However, slump of all concrete mix having Rochelle salt and recycled aggregates was lesser than control mix. With the accumulation of Rochelle salt as a partial substitute of cement in recycled aggregate concrete, workability keeps on decreasing and the decline in workability is more reflective at greater replacement levels. The slump of control mix was 80mm whereas, concrete having 1.25% Rochelle salt slump dropped to 58mm. Reflection of workability in graphical representation of all concrete mixes as slump in mm represented in fig 2.

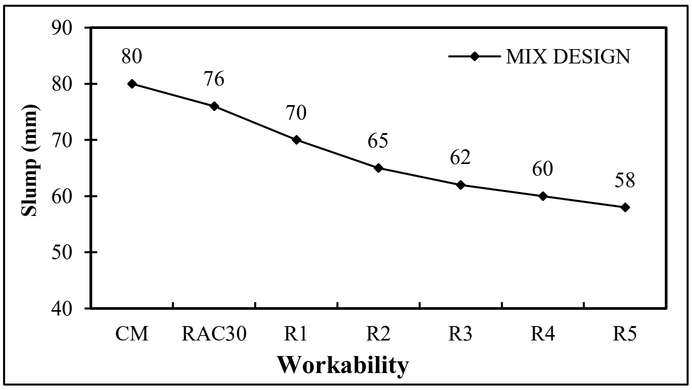

Fig 2: Effect of replacement of recycled aggregates and rochelle salt on the workability of Concrete.

G. Compressive Strength

Compressive strength of all concrete mix was gauged at age of 7 days and 28 days to investigate the effect of Rochelle salt on concrete properties and different observation are given in Table IV.

TABLE IV: COMPRESSIVE STRENGTH TEST RESULTS

Mix Designation	CM	RAC 30	R1	R2	R3	R4	R5
7 Days	21.9	19	26.3	33.4	42.4	34.6	20.6
28 Days	30.2	28.4	38.1	42.4	48	42	29

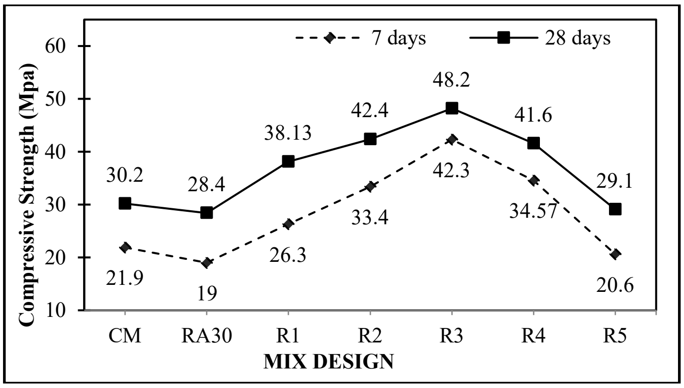

Fig 3: Effect of replacement of cement with rochelle salt in recycled aggregate concrete on Compressive Strength

Figure 3, presents the compressive strength of all mixes, the compressive strength results of RCA is somewhat lesser than the control mix made from same mix proportion. Moreover, addition of Rochelle salt in recycled aggregate concrete shows significant improvement in compressive strength of concrete at all ages as equated to control mix. Addition of 0.75% of Rochelle salt shows higher values of compressive strength on both 7 and 28 days of curing.

H. Split Tensile Strength

Split tensile strength of different batch was assessed after curing period of 7 days and 28 days to study the addition effect of Rochelle salt in recycled aggregate concrete and observations are given in table V. It can be observed that addition of Rochelle salt in recycled concrete has higher splitting tensile strength as compared with both CM and RAC 30 whereas; RA30RS0.75 depicts the highest splitting tensile strength of concrete as shown in fig 4.

TABLE V: SPLIT TENSILE STRENGTH TEST RESULTS

Mix Designation	Split Tensile Strength Obtained (7 days)	Split Tensile Strength Obtained (28 days)
CM	2.3	2.56
RAC 30	2.26	2.50
R1	3.33	4.64
R2	4.38	5.36
R3	5.26	6.14
R4	4.45	5.32
R5	2.72	3.53

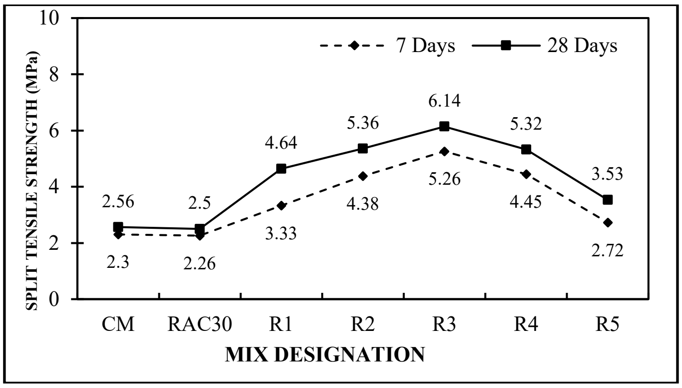

Fig 4: Effect of replacement of cement with rochelle salt in recycled aggregate concrete on split tensile strength.

I. Flexural Strength

The concrete beams flexural strength test has been executed. Following outcomes are acquired throughout the test. Both 7 and 28 days test results are given below in table VI. In specimens of 28 days there is 10% decrease in flexure strength when natural aggregates are replaced with 30% recycled aggregates as shown in fig 5. However, when 0.45% Rochelle salt was used the flexural strength as compared with natural and recycled aggregates increases which is 3.9% and 15.5% respectively. In case of cube specimens of batch RA30RS0.55, RA30RS0.75 and RA30RS1 there is increase in flexure strength of concrete. During the test failure of beam was quite brittle.

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TABLE VI: FLEXURAL STRENGTH TEST RESULTS

Mix Design	Flexural Strength 7 Days (MPa)	Flexural Strength 28 Days (MPa)
CM	2.54	5.29
RAC30	2.33	4.76
R1	4.30	5.50
R2	5.50	6.90
R3	6.00	7.20
R4	5.10	6.60
R5	3.20	4.16

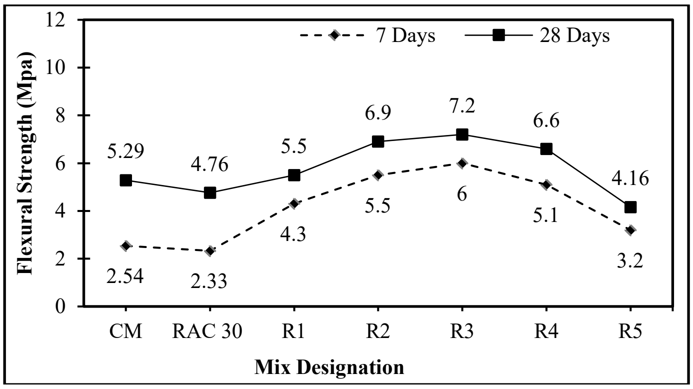

Fig 5: Effect of Replacement of cement with Rochelle salt in recycled aggregate concrete on Flexural Strength.

J. Abrasion Resistance

The abrasion resistance on cubes of size 70mm X 70mm X 70mm has been executed. Succeeding outcomes are achieved throughout the test. The results of abrasion test are shown in table VII

TABLE VII: ABRASION RESISTANCES OF CONCRETE CUBES

Mix Designation	Abrasion Resistance (%)
CM	1.15
RAC 30	1.25
RA30RS0.45	0.76
RA30RS0.55	0.68
RA30RS0.75	0.66
RA30RS1	0.98
RA30RS1.25	1.10

There is 8.6% decrease in abrasion resistance of RAC30 batch mix as compared with control mix as shown in fig 6. Almost similar results are obtained with batch RA30RS1.25 as compared with CM. The abrasion resistance of batch RA30RS0.45, RA30RS0.55 and RA30RS0.75 is 0.76, 0.68 and 0.66 whereas; percentage decrease as compared with CM is 33%, 40% and 42% respectively.

Furthermore, RA30RS1 batch shows 14% decrease in abrasion resistance of concrete. It can be clearly seen that RA30RS0.75 shows most desirable results and less abrasion resistance as compared with all other concrete mix.

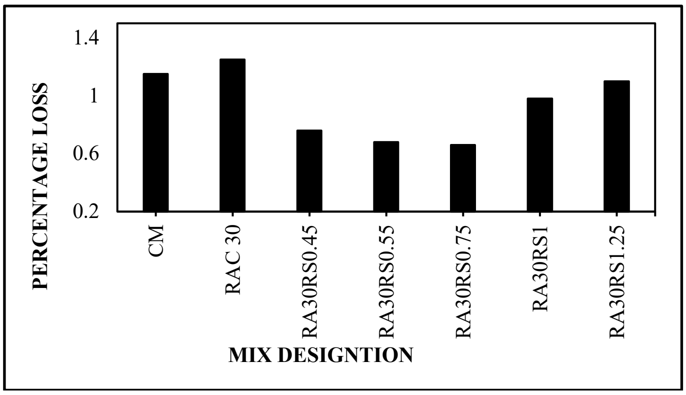

Fig: 6 Effect of replacement of cement with rochelle salt in recycled aggregate concrete on abrasion resistance.

The increase in abrasion resistance of RAC 30 mix may be due to attached mortar to the recycled aggregates which are incorporated in concrete. After that when Rochelle salt was added in concrete the abrasion resistance decreases due to sodium and potassium reaction with alumina silicate which forms rigid and impermeable concrete.

K. Effect of Varying Proportion of Rochelle Salt on Concrete Structure

Different samples such as cubes, cylinders and beams were made with varying proportion of Rochelle salt. Samples were visually examined with the unassisted eye. It was witnessed that during the curing period with increase in proportion of Rochelle salt there was occurrence of heavy efflorescence on the exterior of the samples. Overall, the samples examined experienced cracking and clipping, meaning that sodium ions present in salt admixture could encourage considerable expansion and cracking on material which can usher to complete destruction. This expansion and clipping may also be the reason of decreased strength of concrete. Some samples after 28 days of curing were very fragile; they totally cracked into half, demonstrating that salt crystallization cause damage to the entire cross-section of the concrete sample. Samples having Rochelle Salt above 0.75% shows presence of efflorescence, clipping and expansion on surface.

This behavior of concrete samples at higher proportion of salt admixture is alleged to be correlated to the conception of more prone to salt solution ingress which gives rise to crystallization and to salt-induced cracking, and that a prolonged exposure time is probable to increase the amount of damage.

IV. CONCLUSION

A. Workability of concrete slightly decreases with 30% Recycled aggregates and further decreases with addition of Rochelle salt. This decreased workability of concrete may be due to presence of hydroxyl ions which upsurges the salt solution viscosity present in concrete and hereafter workability decreased. Nonetheless, all the concrete mix has workability within limit for structural practice.

B. The concrete compressive strength decreases slightly with 30% recycled aggregates when Rochelle salt was added in concrete there is upsurge in compressive strength of concrete mix R3 which has 30% RA and 0.75% Rochelle salt. This is due to greater basicity of potassium which induces dense poly condensation favouring superior overall structure and hereafter increase strength. However, further increase in Rochelle salt decreases the compressive strength.

C. The split tensile strength, strength decreases with RA. Whereas, Rochelle replacement of 0.45, 0.55 and 0.75 shows increased strength of cylinders. After that 1% and 1.25% shows decreased strength of concrete.
D. Same trend was seen the flexural strength of concrete decreases with addition of Rochelle salt at 1% and 1.25%. Flexural strength failure was quite brittle. The flexural strength achieved at 0.75% is more as compared with other mix.
E. Abrasion resistance of RA30RS0.55 and RA30RS0.75 is quite similar. Both these mix has lower abrasive resistance as compared with control mix. Whereas, abrasion resistance of RA30RS1.25 is similar to control mix.
F. The samples exposed to greater concentration of Rochelle salt experienced severe damage due to salt crystallization. This designates that higher proportion of Rochelle salt resulted in advanced level of salt crystallization, causing more severe damage. Also, lengthier duration of curing intensify the level of damage, since salt crystallization and accumulation increase with time. Thus, it can be concluded that Rochelle salt in concrete up to proportion of 0.75% can be used whereas; higher proportions will cause damage to concrete and affects its strength.

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