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Comparative Study On Strength And Durability Of Concrete Upon Partial Substitution Of Rice Husk Ash And Pet Powder In Conventional Concrete

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Abstract
The need for concrete is continuously increasing which also leads to a proportional increase in cement demand. The percentage increase of cement manufacturing is 3% per annum. Due to the augmented consumption of cement, the emission of carbon-di-oxide is increasing day by day. CO_2 accounts for approximately 68% of global warming among greenhouse effect. The notorious impacts caused due to the cement utilization gave direction to this research for the partial replacement of rice husk ash and PET powder in the conventional concrete. Comparative study is performed by casting mix with rice husk ash replaced at 0% to 40% at 5% interval and accordingly other mixes with PET powder replaced with 0% to 40% at 5% interval by weight of cement in the concrete and cured for 28, 56, and 90 days. Experimental investigations were carried out to determine mechanical parameters like compressive strength, split tensile strength, flexural strength, and durability aspects like resistance to chloride ion permeability, acid attack. Based on the research, it was concluded that rice husk ash can be replaced up to 40% and PET powder up to 15% in the concrete in terms of both strength and durability aspects. Rice husk ash replacement resulted in the maximum later strength achievement of 75 MPa at 30% replacement while the PET powder incorporation resulted in maximum early strength attainment of 62 MPa at 15% replacement.
Key words: Rice hush ash, PET powder, compressive strength, split tensile strength and acid attack.

1. Introduction

Concrete consists of cement, aggregates, and water, as well as an admixture that is often used in production. Previous researchers found that, with the addition of fillers like powdered marble, fly ash and lime stone, ternary mix is generated which has the lower strength attainment for 28 days curingage due to the gradual pozzolanic action [1]. Limestone is a significant ingredient in cement manufacturing. One ton of cement production results in about 0.90 tons of CO_2 emission into the atmosphere [2]. In future, the demand for cement will most likely outpace demand for concrete. In 2023 India produced about 411 (MT) of cement on a yearly basis. Based on the research investigations, it was concluded that dense and close spacing of pozzolana is the viable reasons for the
strength enhancement relative to the control concrete [3]. CO_2 released from the cement manufacturing process is a major area of concern, as it may be reduced by utilizing supplementary materials [4]. The Ministry of Environment, Forest and Climate Change, have a serious influence on rice husk ash consumption and PET powder consumption in India [5, 6]. Considerations of profit reduction, shareholder mindset, variations of rice husk ash quality and slower strength development are all factors that affect the usage of rice husk ash in concrete in India. India has a large abundance of rice husk ash and its attributes are within the permitted limits for usage in concrete as per the Indian Standards [7]. rice husk ash concrete performance is strongly influenced by the physical and chemical composition. According to ASTM standards. In the search of adopting this environmentally friendly concrete, which contains 80% to 90% rice husk ash in total cementitious material, experimental research was conducted on flexural behaviour of rice husk ash beams, it was found that deflection of RCC beams is within acceptable limits of IS 456 in case of service loads [8]. One of the back drops of rice husk ash utilization is low strength attainment during early stages. To eradicate this, study of strength parameters upon partial replacement of PET powder is initiated. Understanding the behaviour of various binary mixes can be able to develop efficient ternary mix.

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The disposal of agro-based industry waste is a severe environmental issue, as the majority of final wastes end up in landfills, which not only wastes productive land but also damages the environment. Rice husk ash has been researched for its benefits on concrete performance. Physical impacts are mostly related with their impact on the homogeneous mixture's packing properties. Chemical impacts, on the other hand are associated to their potential to provide amorphous silica that will react with Portlandite in the presence of water during cement hydration [9]. Fineness of rice husk ash aided in filling voids among the binder content and aggregates. The high rice husk ash fineness, which fills the gaps between the cement and aggregates, may be one of the causes for rice husk ash concrete's early compressive strength development. Later in life, the pozzolanic reaction between reactive silica in rice husk ash and calcium hydroxide produced during the cement hydration process resulted in the formation of extra calcium silicate hydrate, which improved the interface binding between pastes and aggregates. Based on the experimental investigation performed on the rice husk ash blended concrete, it was concluded that the presence of finer rice husk ash particles induced discontinuous pores in the matrix and the micro-pores were present in the concrete filled by these finer particles [10]. In view of evaluating a composed mix design, the aggregates shouldbe accommodated denser, in which packaging density plays a vital role in the minimization of binder quantity as well as the creep and shrinkage in the concrete [11].
The above-mentioned literature gave scope to this research. The investigation involves in the determination of mechanical properties of hardened concrete like compressive strength using cubes of 150 mm and flexural strength test using prisms of size 100x100x500 mm for both the rice husk ash and PET powder mixes for the replacements of 0% to 40% at an interval of 5%.

2. Experimental Procedure

Concrete mixes were produced by Ordinary Portland cement of 53 grade confirming to the specifications of IS 12269: 1987 [12] which was partially replaced with rich husk ash at 0% to 40% by 5% intervals and PET powder at 0% to 40% by 5% intervals. The chemical composition of OPC, rice husk ash and PET powder was tabulated in Table 1. The physical properties of the cement binder and the cement substitutes were tabulated in Table 2. Locally available river sand is used according to the specifications of IS 383 (1970) [13]. Coarse aggregates of sizes 12, 20 mm are used respectively. Physical properties of fine and coarse aggregates were tabulated in Table 3. Gradation curves of fine and coarse aggregate were plotted in figure 1 respectively. Two types ofmixes were prepared designating as (RHA0, RHA5, RHA10, RHA15, RHA20, RHA25, RHA30, RHA35 and RHA 40). In addition to those mixes, PET powder mixes are cast which are represented as (PET0, PET5, PET10, PET15, PET20, PET25, PET30, PET35 and PET40). Mix design details of rice husk ash concrete are tabulated in the table 4 and table 5 represents mixed design of PET powder concrete at 400 kg/m^3 at 0.44 water/binder ratio.

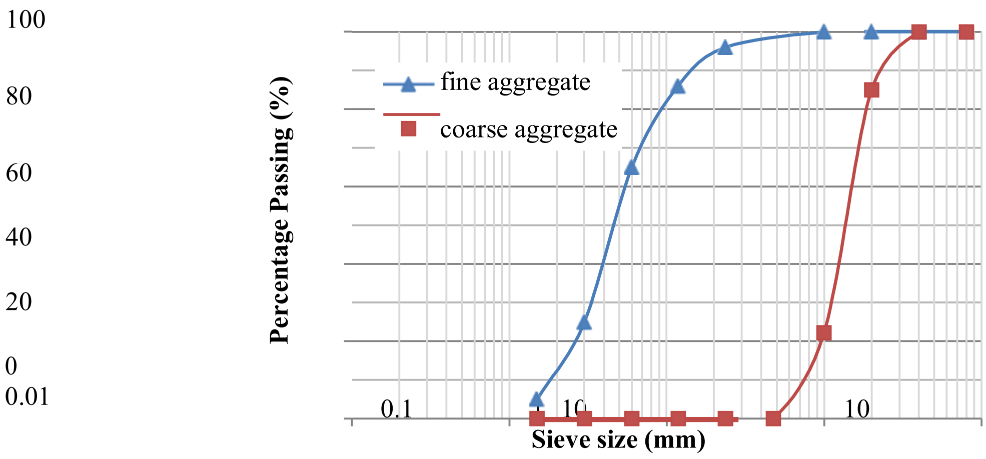

Figure 1 Gradation curve

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Table 1. Chemical composition.

Compound	OPC (%)	RHA (%)	PET (%)
SiO_2	19.62	49.1	67.6
Al_2O_3	5.47	14..6	18.9
Fe_2O_3	3.24	2.5	3.62
CaO	62.20	0.6	0.71
MgO	3.62	1.2	1.62
SO_3	2.41	0.15	1.2
Na_2O	0.7s	0.08	0.15
P_2O_5	0.8	0.45	1.2
LOI	1.63	1.9	1.2

Table 2. Physical properties of materials.

Property	OPC	RHA	PET
Specific gravity	3.10	2.3	2.8
The average grain size(μm)	22.4	21	20
Specific surface area(cm^2/g)	3246	3502	3780
Normal consistency	28	36	33
Initial setting time (min)	30	60	55
Final setting time (min)	210	230	245

Table 3. Properties of fine and coarse aggregates.

Physical property	Fine aggregates	Coarse aggregates
Specific gravity	2.55	3.75
Fineness modulus	2.35	6.15
Unit weight (kg/m^3)	1715	1665

Table 4. Mix design details for rice husk ash concrete.

Mix Designation	% of replacement	Cement (kg)	RHA (kg)	Water(kg)	Fine aggregate (kg)	Coarse aggregate (kg)
RHA0	0	400	0	160	759.55	1139.3
RHA5	5	380	20	160	756.58	1134.87
RHA10	10	360	40	160	753.63	1130.4
RHA15	15	340	60	160	750.66	1125.99
RHA20	20	320	80	160	747.71	1121.7
RHA25	25	300	100	160	744.74	1117.12
RHA30	30	280	120	160	735.87	1103.8
RHA35	35	260	140	160	738.82	1108.24
RHA40	40	240	160	160	729.95	1094.9

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Table 5. Mix design details for PET powder concrete.

Mix Designation	% replacement	ofCement (kg)	PET (kg)	Water (kg)	Fine aggregate (kg)	Coarse aggregate (kg)
PET0	0	400	0	160	759.55	1139.3
PET5	5	380	20	160	756.58	1134.87
PET10	10	360	40	160	753.63	1130.4
PET15	15	340	60	160	750.66	1125.99
PET20	20	320	80	160	747.71	1121.7
PET25	25	300	100	160	744.74	1117.12
PET30	30	280	120	160	735.87	1103.8
PET35	35	260	140	160	738.82	1108.24
PET40	40	240	160	160	729.95	1094.9

3. Testing

3.1 Compressive strength

Compressive strength of hardened concrete is termed as the potential for concrete to sustain before failure occurs. It can be determined by the ratio of failure load to the c/s area of the specimen when itis placed in UTM. Units are MPa or N/mm^2 and this test attributes majorly to determining the strength of the specimen which confirms the specifications of IS 516:1959. By this test, the overall characteristics of the concrete can be understood. Figure 2 shows the testing of specimens respectively.

Figure 2. compressive strength test

3.2 Split tensile strength

This test is also known as a diametrical compression test which was done to evaluate the tensile strength of concrete indirectly. Specifications corresponding to IS 5816 (1999) were followed and 150mm x 300 mm height cylinders were utilized. The loading should be applied at 2.4 MPa and the failure load is noted. Tensile strength is evaluated using the formula

□= 2□/□

Where T is split tensile strength (MPa)P = maximum applied load (kN)
L= length of specimen (m) and
d = diameter of the specimen (m)

3.3 Flexural strength

The prisms of 100 x 100 x 500 mm size specimens are subjected to flexural strength test as per IS: 516 –

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2002. The loading rate was maintained as 1.8 KN per minute for the entire loading period.
Expression for calculating flexural strength is f_b= PL/bd^{2}Where f_b is the flexural strength (MPa)
P is the Failure load applied to the specimen (kN)
d = length of the specimen at the time of failure (mm)

3.4 Acid attack

Concentrated sulphuric acid (H_2SO_4) of 5% with a Ph of 2 was used and cubes are imposed to acid immersion at curing ages like 28, 56 and 90 days as per ASTM C1898–20. After completing the requisite immersion in the acid, the cubes were evaluated for residual weight and residual strength. For evaluating the strength loss, after the completion of immersion period, specimens are subjected to compressive strength test.

3.5 Rapid chloride permeability test (RCPT test)

The RCPT device is used to determine the resistance to chloride ion transfer. It is one of the vital tests to determine the durability of concrete in aggressive environment. The specimen was fitted between two cells containing 0.3M NaOH solution and a 3 percent NaCl solution, with a diameter of 0.1 mm and a height of 0.05 mm.

4. Results

4.1 Compressive strength

After performing compressive strength tests on the specimens with both rice husk ash and PET powder, the results were plotted in figure 3 and figure 4 respectively. From the figure 3, it is clear that incorporation of rice husk ash resulted in the high strength attainment of 58.7 MPa at 28 days and 74.3 MPa at 90 days while the percentage of strength gain for RHA30 mix during early (28 days) and later curing age (90 days) is 27% and the % gain of strength during 28, 90 days for RHA0 mix is 18%. The addition of rice husk ash in the concrete has the potential for dense packing of the particles by which high strength attainment is achieved. Early strength attainment is gradual when compared to the later strength gain as the pozzolanic action is gradual for rice husk ash.

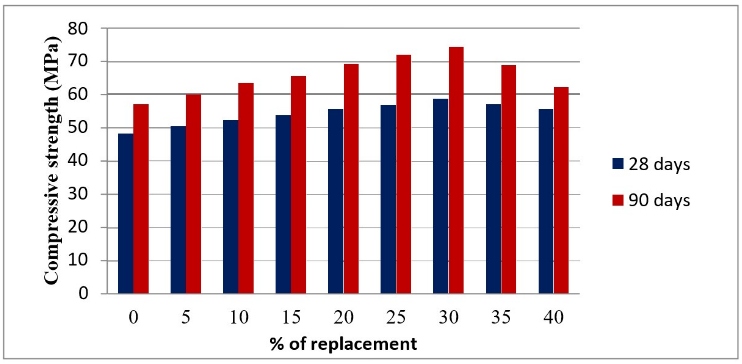

Figure 3. Compressive strength of rice husk ash specimens

The compressive strength attained for conventional concrete mix during 28, 90 days is 46.5 and 54.87 MPa while the % gain of strength during early and later curing ages is 18%. Concrete mix with 20% PET powder replacement (PET20) resulted in high early strength of later strength of 60.1 MPa and 70.12 MPa at later ages, while the % gain of strength during 28, 180 days is 17% which is plotted in figure 4. Early strength attainment mostly occurred in the PET20 mix while the higher later strength attainment was exhibited in RHA30 mix. The presence of elongated spheres form of Mullite yielded in the early strength attainment as the pozzolanic action of PET powder is rapid when compared to the rice husk ash.

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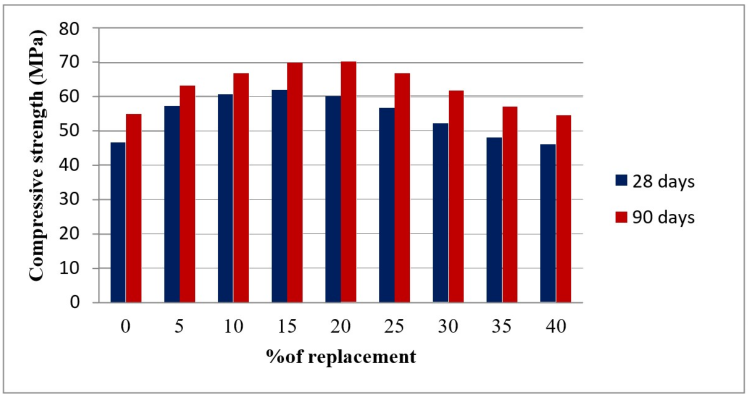

Figure 4. Compressive strength of PET powder specimens

4.2 Split tensile strength

The test results obtained after performing this test is plotted in figure 5. Split tensile strength of conventional concrete at 28, 90 days is 3.93 MPa and 3.43 MPa for (RHA0) mix, while the % gain of strength for (RHA0) mix is 14% and 17%. At 30% rice husk ash replacement, the maximum resistance against tension achieved by the specimen at 28, 90 days is 4.32 and 5.45 MPa, while the % gain of strength during these days is 27%.

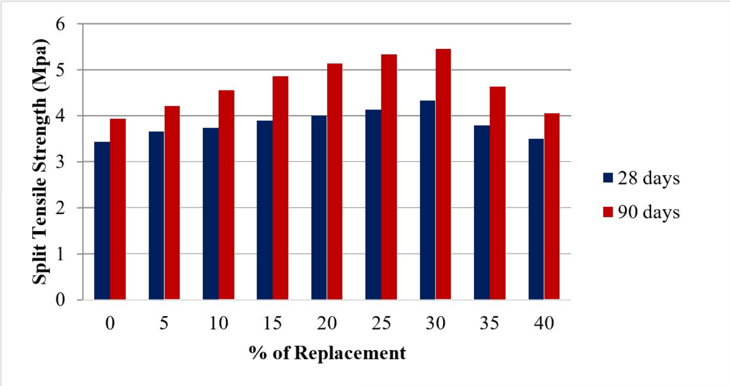

Figure 5. Split tensile strength of rice husk ash specimens

Figure 6 represents the split tensile strength of concrete, which is incorporated with PET powder from0% to 40% replacements. As shown in the figure, the strength attained for conventional concrete (PET0) at 28, 90 days is 3.45 MPa and 4.05 MPa while the % gain of strength is 17%. For 20% PET powder replacement (PET20) mix, strength against tension during 28, 180 days is 4.39 MPa and 5.17 MPa while the % gain of strength is 18%.

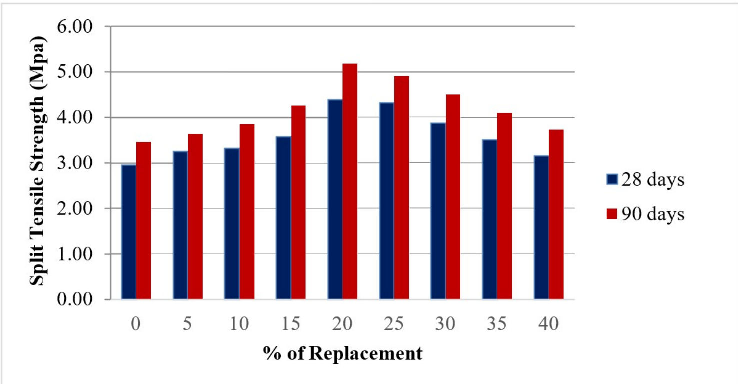

Figure 6. Split tensile strength of PET powder specimens

4.3 Flexural strength

Resistance against bending is performed for both the rice husk ash and PET powder concrete with 0% to 40% replacements and the test results were plotted in figure 7 and figure 8 respectively. The strength against

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bending achieved by conventional concrete mix (RHA0) is 5.32 MPa and 5.76 MPa while the % gain of strength during 28, 90 days is 8%. Mix with 30% rice husk ash replacement (RHA 30) yielded strength of 6.32 MPa at 28 days and 6.6 MPa at 180 days while the % gain of strength during early and later curing ages is 7%.

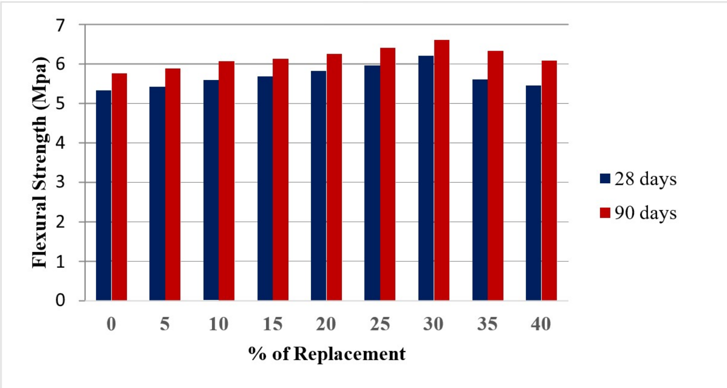

Figure 7. Flexural strength of rice husk ash specimens

Figure 8 represents the flexural strength attained by the concrete blended with PET powder from 0% to 40% by 5% interval. From the figure, it is clear that the replacement of PET powder at 20% in the concrete resulted in the strength attainment of 8.1 MPa at 28 days and 9.18 MPa at 90 days while the % gain of strength for this mix (PET20) is 13%. With the addition of PET powder, % gain of strength is enhanced by 6% when compared to the % gain of strength attained by rice husk ash concrete. Finer particles accommodated the space between cement and coarse aggregate which resulted in strength attainment against bending.

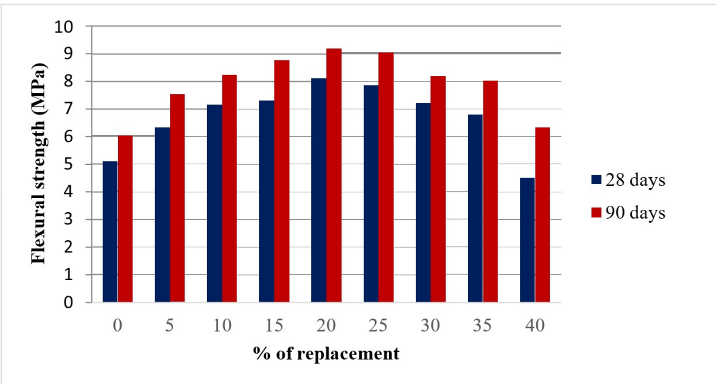

Figure 8. Flexural strength of PET powder specimens

4.4 Acid attack

The deteriorated specimen after immersing in the sulphuric acid solution at 90 days is represented in the figures 9 and 10 respectively. It is clear from the figure that incorporation of rice husk ash resisted the acid attack effectively when compared to the PET powder concrete specimens. In the absence of pozzolanic materials, precipitation of reactive salts will increase and the concrete yields will degrade layer bylayer and thus acid attack occurs. Concrete with rice husk ash comprises alumina oxide in major quantities compared to the PET powder. This alumina resists the acid attack and this protection is continued for long term curing ages.

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Figure 9. Rice husk ash specimens after immersing them in acid for 90 days

Figure 10. PET powder specimens after immersion in acid for 90 days

Percentage loss of strength for concrete with rice husk ash added at 0% to 40% at 5% interval after acid attack was subjected to compressive strength test and the results were plotted in figure 11 which shows that conventional concrete has the % loss of strength at 28, 90 days is 12.85% and 15.25%.
% loss of strength is being decreased with the addition of rice husk ash and at the optimum percentage of replacement (RHA30) mix; it is 10.8% and 9.9% while the % loss of strength is enhanced by 9%.

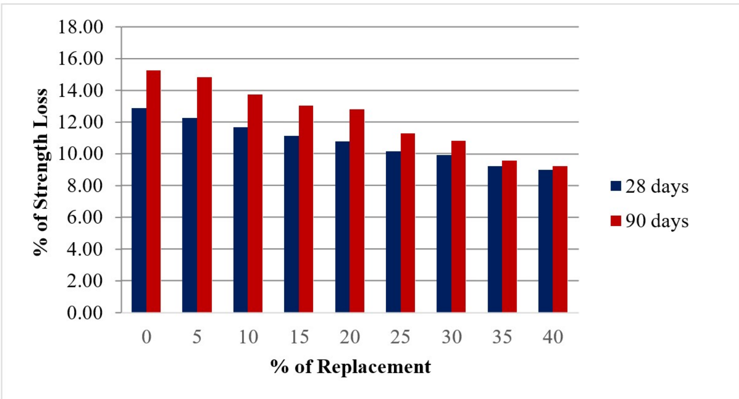

Figure 11. % of strength loss of rice husk ash specimens

Figure 12 represents the % loss of strength for PET powder concrete when it is replaced with 0% to40% at an interval of 5% after immersing in sulfuric acid for 28, 90 days. From the figure, it is clear that the addition of PET powder resisted the acid attack and resulted in low strength loss. Conventional concrete has the % loss of strength during 28 and 90 days is 13.2% and 16.78% while the % loss of strength enhanced during 28, 90 days is 27% while at optimum replacement of PET powder (PET20),
% loss of strength at 28 days is 9.45% and 14.06% at 90 days. % loss of strength is the maximum in the case of optimum percentage of replacement.

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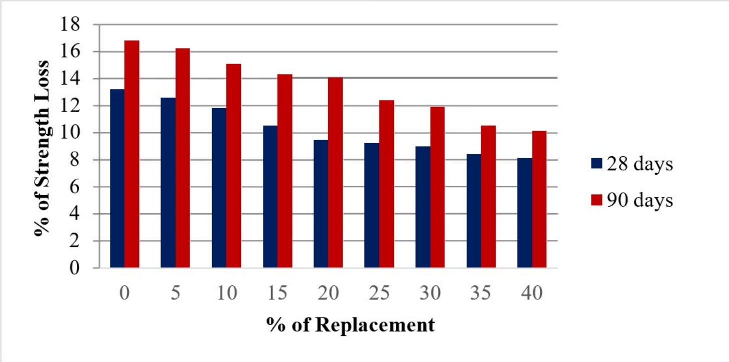

Figure 12. %of strength loss for PET powder specimens

4.5 RCPT test

The resistance against permeability of chloride ion for the concrete with rice husk ash at 0% to 40% by 5% interval is plotted in the figure 13. Dissolution of ions from high to lower concentration leads to the degradation of layer thus minimizing the resistance of permeability of the concrete. Figure 13 represents the test results obtained after performing rapid chloride permeability test and for theconventional concrete, the charge passed at 28 days is 1565.8 and 1471.85 coulombs and percentage gain of resistance against permeability is 7%. At 30% rice husk ash replacement (RHA30) mix, the charge passed at early (28 days) is 1315.27 and 1105.83 coulombs at 90 days and % gain of resistance against permeability during these days is 19%.

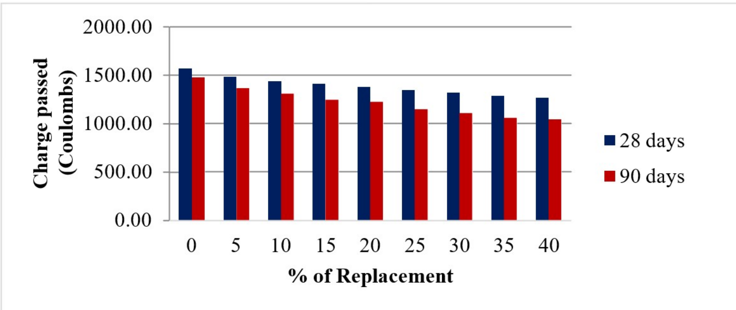

Figure 13. RCPT test results for rice husk ash

Figure 14 represents the test results obtained after performing RCPT test after 28, 90 days curing ages and the charge passed at 28 days for conventional concrete (PET0) is 1680.5 coulombs and 1663.7 coulombs for 90 days while the % gain of resistance against permeability attained during these days is 1%. For concrete with PET powder at 20% replacement (PET20) mix, charge passed at 28, 90 days is 1446.8 and 1280.42 coulombs while the % gain of resistance against permeability during 28, 90 days is 13%. Compared to PET powder concrete, concrete with rice husk ash effectively resisted the permeability of chloride ion.

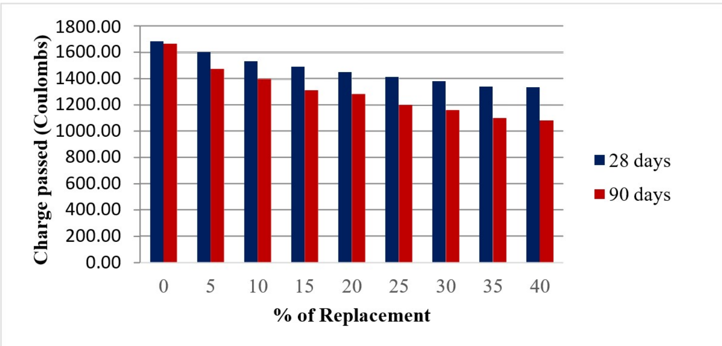

Figure 14. RCPT test results for PET powder specimens

5. Conclusions

- Crystallinity is imparted in the rice husk ash and PET powder specimens when it is blended with binder

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which results in strength attainment.

- Finer particles present in the PET powder specimens tend to react with celite compound along with other hydration products to impart early strength and durability properties of the concrete.
- Mix of RHA30 and PET20 attained high strength and durability relative to all the mixes.
- Rice husk ash and PET powder specimens act as micro-fillers and accommodate the pores between cement matrix and aggregates. This leads to achieving dense concrete which can resist aggressive environment.
- Rice husk ash and PET powder specimens are the alternate cementitious materials. In the presence of rice husk ash, this conversion consumes more duration when compared to the PET powder specimens which is the main reason for low early strength attainment of rice husk ash concrete.
- Rice husk ash, which has back drop of slow strength attainment, can be accompanied by the PET powder specimens which is comparatively rapid in attaining strength at early ages of curing.
- Utilization of these alternate cementitious materials as replacement of cement in the concrete not only enhances the strength and durability properties but also reduces the adverse impact on the environment.

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