STUDIES ON CERAMIC WASTE, FLY ASH, SILICA FUME IN POROUS CONCRETE

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ABSTRACT. Ceramic products are part of the essential construction materials used in most buildings. Some common manufactured ceramics include wall tiles, floor tiles, sanitary ware, household ceramics and technical ceramics. They are mostly produced using natural materials that contain high content of clay minerals. However, despite the ornamental benefits of ceramics, its wastes among others cause a lot of nuisance to the environment. This paper presents an experimental study on engineering properties of porous concrete using ceramic waste, fly ash and silica fumes as replacement of aggregates and cement. The concrete specimen were tested for compressive strength, flexural strength, split tensile and water absorption test. Ceramic waste was varied as 10%, 20% and 30% as replacement of coarse aggregate. Fly ash was replaced with cement by 20%, 30% and 40%. Silica fumes replacement was varied as 10%, 20% and 30% as replacement of cement. Compressive strength decreased with increase in replacement of fly ash content, silica fume content and also for ceramic waste content for a given replacement. Although this strength increased for 28 days curing period for all replacements. The water absorption test showed that the absorption rate increases with an increase in replacement percentage. The sample with 40% fly ash as replacement has higher absorption than a sample with 30% fly ash as replacement. The ceramic waste replacement showed the least absorption rate among all the three replacement under study, with 1.56% being the absorption rate for 30% replacement and 1.43% for 10% replacement of coarse aggregate by ceramic waste.

Keywords: Ceramic waste, Fly ash, Silica fume, Compressive strength, flexural strength, Split tensile strength, water absorption.

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INTRODUCTION

Rice husk is an important waste material from the agricultural industry. It is a major source of environmental pollution since there are not very effective methods which can be used for its disposal. The compressive strength and flexural strength is increased up to 10% replacement of cement by Rice Husk Ash (RHA), after this percentage, the strength starts to decrease[1]. The replacement of cement by Rice Husk Ash (RHA) up to 20% does not show any variable increase or decrease in strength but after 20% replacement the compressive strength increases due to high w/c ratio required to maintain the workability of concrete [2]. The rubber tyre waste can be used as a replacement of aggregates for a certain limit. The concrete showed a lesser compressive strength, split tensile strength and flexural strength as compared to conventional concrete. The rubberized concrete cost is less than the cost for conventional concrete [3]. Concrete casted using crumb rubber as a full replacement to sand shows a significant reduction in concrete strength compared to conventional concrete. However, the ductility observed was significant. India depends on Thermal Power as its main source, thus there is an increase in power requirement every year. Present scenario of our country shows 75 % of the country's total installed power generation is thermal of which coal-based generation is 90%. Use of coal brings a huge amount of ash every year. Fly ash having particle size similar to cement particles, can be used as a replacement of cement [4]. When fly ash percentage is increased to 20% in concrete, the permeability is decreasing but when this fly ash content is increased to 50% in concrete, the permeability gets increased which is similar to no fly ash pervious concrete [5]. Investigation on the properties of the pervious concrete showed that the porosity of the pervious concrete was not affected much when 50% of the cement was replaced by fly ash and also the compressive strength decreased with increase in fly ash content [6]. The fly ash concrete containing steel fibre properties were studied and it was inferred that it improves the tensile strength properties, drying shrinkage and freeze-thaw resistance [7]. The replacement of silica fumes was done so as to see an increase in strength but on the contrary, it showed a decrease in strength as the replacement increased. Silica fumes being 100 times smaller than cement leads to the reduction in porosity. The least permeable concrete that can be obtained is when the replacement of cement by silica fumes is limited to 15% [8]. A study showed that the permeability reduces when the replacement is 8% and it keeps on decreasing from 8% to 12%. After this replacement, the permeability increases with increase in water cement ratio [9]. It is concluded that the permeability and strength of concrete are optimum when the replacement percentage of cement by silica fumes varies from 8% to 12% [10]. The furnace slag can be used as an aggregate in concrete. The study on hardened concrete using slag aggregate and natural aggregate was studies and experiment showed that slag aggregate concrete achieves higher values of compressive strength, split tensile strength and flexural strength and also the modulus of elasticity is improved [11]. The Compressive strength of porous concrete depends on the porosity of concrete. Reduction in aggregate size decreases the porosity of concrete and hence the strength of concrete gets increased [12]. Ceramic waste and demolition waste can save up to 40% fine aggregate while making rigid pavement surfaces [13]. The ceramic waste ground to an appropriate fineness can be considered as a pozzolonic material suitable for the replacement of a part of Portland cement in concrete. The Waste ceramic material used as recycled material in concrete production lessen the CO2 burden on the environment and is more cost effective as compared to Portland cement [14]. The ceramic waste is found to be suitable for use as a substitution for fine aggregates as well as for coarse aggregates. They were found to be performing better in properties such as compressive strength, permeability, density and durability than conventional concrete [15]. The use of waste ceramic tiles causes no negative effect in properties of concrete. The optimal use of ceramic waste as coarse aggregate is found to be 10% to 30%. At this replacement, the compressive strength increases and also there is a reduction in unit weight of concrete [16].

MATERIALS

Cement

OPC 53 grade Cement was used for making concrete specimen. The specific gravity of the cement was found to be 3.12. The initial and final setting time was found to be 160 minutes and 210 minutes respectively.

Silica Fumes

The specific gravity of silica fumes was found to be 2.26. The silica fumes owing to its small particle size and large surface area, it requires high water content but here the water cement ratio is fixed as 0.35 and test are performed using the ratio as 0.35. The concrete containing silica fumes has got better workability than conventional concrete and it also protects the concrete against saline water conditions.

Ceramic Waste

The specific gravity of ceramic waste was found to be 2.68. The ceramic tiles of size 762mm X 457.2mm and with thickness 4mm were crushed and made to pass through a sieve size of 10mm. The replacement was done as 10% 20% and 30% by replacement of coarse aggregate.

Aggregates

The size of the coarse aggregate was taken from 12mm to 20mm. The specific gravity of coarse aggregate was found to be 2.70 and its water absorption was found to be 0.6%. The specific gravity of fine aggregate was found to 2.6 and its water absorption was found to be 1.07%.

COMPOSITION AND PREPARATION OF MIXTURE

The porous concrete was designed for M20 grade of concrete by using mix design code IS10262-2009 [17].The samples were prepared by replacing cement by fly ash, silica fumes, and ceramic waste. Coarse aggregate was placed in the mixing tray and then fine aggregate was added to coarse aggregate and mixed for 1-2 minutes. The cement as per the mix design was added to the mixing tray. The mixture was then mixed in dry form for 1-2 minutes and water was added as per mix design. The mixture was mixed well for 4-5 minutes and then the mixture was filled in the mould. The moulds filled with the freshly prepared concrete mixture was not compacted or agitated as it would fill the voids. After casting, each specimen was allowed to stand for 24 hours. The demoulded samples were kept in water for 7 days and 28 days curing period. The specimen were named as A1, A2, etc. so as to indicate that what is the replacement percentage and what material is being used as a replacement. Table 1-3 shows the design mix ratio for various replacements of fly ash, silica fume and ceramic waste.

Fly ash

The fly ash mixture was prepared by taking 90% coarse aggregate and 10% fine aggregate so as for better workability of the concrete mix. The cement was replaced by fly ash by percentage varying from 20%, 30% and 40% respectively. The concrete mix was prepared using water-cement ratio as 0.35. There were 2 samples prepared each for 7 days curing period as well as for 28 days curing period for a given percentage replacement. The same procedure was followed for flexural strength, split tensile strength test.

Silica Fumes

The Silica Fume replaced concrete mixture was prepared by taking 90% coarse aggregate and 10% fine aggregate so as for better workability of the concrete mix The cement was replaced by silica fumes with the percentage varying from 10%,20%, and 30%. The water-cement ratio was taken as 0.35. There were 2 samples prepared each for 7 days curing period as well as for 28 days curing period for a given percentage replacement. The same procedure was followed for flexural strength, split tensile strength test.

Ceramic Waste

The ceramic waste replaced concrete mixture was prepared by taking 80% coarse aggregate, 10 % fine aggregate and 10% ceramic waste. The coarse aggregate was replaced by ceramic waste and the replacement was done as 10%, 20%, and 30%. The water -cement ratio was taken as 0.35. There were 2 samples prepared each for 7 days curing period as well as for 28 days curing period for a given percentage replacement. The same procedure was followed for flexural strength, split tensile strength test.

Table 1 Mix Proportions- Fly Ash

FLY ASH (%)	FLY ASH	WATER	CEMENT	FINE AGGREGATE	COARSE AGGREGATE
20%	0.245	0.35	1	0.36	3.43
30%	0.43	0.35	1	0.43	4.0
40%	0.66	0.35	1	0.44	0.66

Table 2 Mix Proportion-Silica Fume

SILICA FUME (%)	SILICA FUME	WATER	CEMENT	FINE AGGREGATE	COARSE AGGREGATE
10%	0.111	0.35	1	0.304	2.84
20%	0.25	0.35	1	0.33	3.16
30%	0.43	0.35	1	0.38	3.57

Table 3 Mix Proportion - Ceramic Waste

CEREMIC WASTE (%)	CEREMIC WASTE	WATER	CEMENT	FINE AGGREGATE	COARSE AGGREGATE
10%	0.259	0.35	1	0.27	2.32
20%	0.517	0.35	1	0.27	2.07
30%	0.770	0.35	1	0.27	1.81

EXPERIMENTAL PROGRAMME

Compressive Strength Test

Compressive strength test was done on a specimen of size 100mm x 100mm x 100mm. The strength was determined as per IS:516 [18]. The cube surface was kept under the compression testing machine. The load bearing surface was cleaned with the help of a cloth. The cubic specimen were put under compression load such that the bearing surfaces are the surface that is opposite to the sides of the cast i.e. the side surface and not the top and bottom surface. The load was applied gradually and not with any vibrations or sudden impact. The load was applied at the rate of 15N/mm2/min and the load at which the specimen failed was recorded. The compressive strength was calculated by dividing the load at failure by cross-sectional area of the specimen. Table 4 shows the compressive strength for 7 days and 28 days curing period.

Compressive strength= P/A

P= Load at failure

A= Cross Sectional Area (Here 100mm x 100 mm)

Table 4 Compressive Strength of cubes

MIXTURE	% FLY ASH	7^{TH} DAY	28^{TH} DAY
Mixture A1	0%	15.78	18.23
Mixture A2	20%	12.69	14.44
Mixture A3	30%	11.10	13.62
Mixture A4	40%	10.44	13.2
	% silica fumes		
Mixture B1	0%	9.1	10.78
Mixture B2	10%	7.2	8.71
Mixture B3	20%	6.7	8.30
Mixture B4	30%	5.7	6.78
	% ceramic waste		
Mixture C1	0%	10.4	11.74
Mixture C2	10%	8.91	9.4
Mixture C3	20%	7.63	8.97
Mixture C4	30%	7.3	7.9

Flexural Strength Test

Flexural strength for the porous concrete cubes was calculated as per ASTM- C293 [19]. The specimen size was taken as 500mm x 100mm x 100mm. The strength was calculated for a curing period of 7 days and 28 days. The specimen was tested using the flexural testing machine. The bearing surface of the machine was cleaned with the help of a cloth. The specimen was subjected to uniform loading condition. The axis of the specimen was clearly aligned with the axis of the loading device. The load was increased gradually until the specimen failed. The load at failure was recorded. Table 5 shows the flexural strength for 7 days and 28 days curing period.

The flexural strength was calculated using formula

$Fb = PL/bd^2$

Here,

P= Load at failure (Maximum load applied in kg)

L= Length of the supporting span in cm

b= measured width in cm of the specimen

d= measured depth in cm of the specimen at the point of failure.

Table 5 Flexural Strength on Prism

MIXTURE	% FLY ASH	7^{TH} DAY	28^{TH} DAY
Mixture A1	0%	6.71	7.45
Mixture A2	20%	5.43	6.21
Mixture A3	30%	4.77	5.12
Mixture A4	40%	4.22	4.07
	% silica fumes		
Mixture B1	0%	6.43	6.78
Mixture B2	10%	5.13	5.77
Mixture B3	20%	4.89	5.26
Mixture B4	30%	4.37	4.82
	% ceramic waste		
Mixture C1	0%	5.21	6.50
Mixture C2	10%	3.77	4.58
Mixture C3	20%	3.36	4.12
Mixture C4	30%	3.10	3.79

Split Tensile Strength

The split tensile strength of the concrete specimen was determined as per ASTM- C496 [20]. The specimen were cylindrical in shape and were of size 200mm in height and 100 mm in diameter. The lines were drawn on the diameter of the sample specimen with the help of a chalk and a scale. The lines were drawn so that the specimen is aligned with the bearing surface of the testing machine. The load at which the specimen failed was recorded and the strength was calculated for a curing period of 7days and 28 days respectively. Table 6 shows the split tensile strength for 7 days and 28 days curing period.

Table 6 Split Tensile Strength Test for 7 days and 28 days curing period

MIXTURE	% FLY ASH	7TH DAY	28TH DAY
Mixture A1	0%	2.14	2.78
Mixture A2	20%	1.35	1.39
Mixture A3	30%	1.23	1.29
Mixture A4	40%	1.19	1.22
	% silica fumes		
Mixture B1	0%	2.12	2.91
Mixture B2	10%	1.22	1.37
Mixture B3	20%	1.16	1.28
Mixture B4	30%	1.05	1.196
	% ceramic waste		
Mixture C1	0%	1.74	2.31
Mixture C2	10%	0.98	1.07
Mixture C3	20%	0.87	0.97
Mixture C4	30%	0.83	0.86

Water Absorption test

The samples for various replacement fly ash, silica fumes, and ceramic waste are tested for water absorption test. The cubic samples were prepared and kept for 7 days curing period. The samples were then kept in the oven at 105°C for 72 hours. The samples were then immersed in water after cooling them for 4-5 hours. The samples were immersed in water for 24 hours. The weight of the samples after over drying (W1) and after taking them out of water (W2) was recorded. The difference in weight showed the water absorbed by various samples for 7 days curing period. Table 7 shows the water absorption by different replacement samples.

Table 7 Water Absorption Test for various Replacement

% REPLACEMENT	WEIGHT W1(gm)	WEIGHT W2 (gm)	[(W2-W1)/W1]*100 %
20% Fly Ash	2072.5	2126.5	2.60%
30% Fly Ash	2014.5	2075.5	3.028%
40% Fly Ash	1954.5	2026.0	3.65%
10% Silica Fumes	1661.7	1709.5	2.87%
20% Silica Fumes	1658.5	1712.0	3.23%
30% Silica Fumes	1732.0	1793.5	3.55%
10% Ceramic Waste	2222.6	2254.5	1.43%
20% Ceramic Waste	2167.5	2200.0	1.49%
30% Ceramic Waste	2107.5	2140.3	1.56%

DISCUSSION OF TEST RESULTS

Compressive strength test

Compressive strength on fly ash concrete

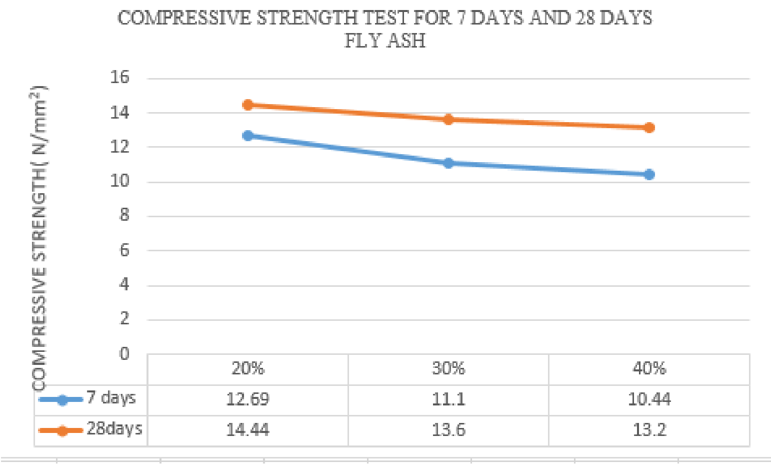


Figure 1 Compressive Strength for Fly ash replacement

In figure 1, the compressive strength of the fly ash decreased for an increase in the percentage of replacement of cement by fly ash. The strength however increased for the 28 days curing period but again the strength decreased for an N/mm^2 increase in replacement of cement by pond ash. The strength for 20% replacement is 12.69 N/mm^2 and this reduces to 10.44 N/mm^2 for 40% replacement. The strength for 28 days 20% replacement of cement by fly ash there is just an increase of 13.79% in strength. For 40% replacement, the strength increases by 26.43% for curing period of 28 days.

Compressive strength on silica fume concrete

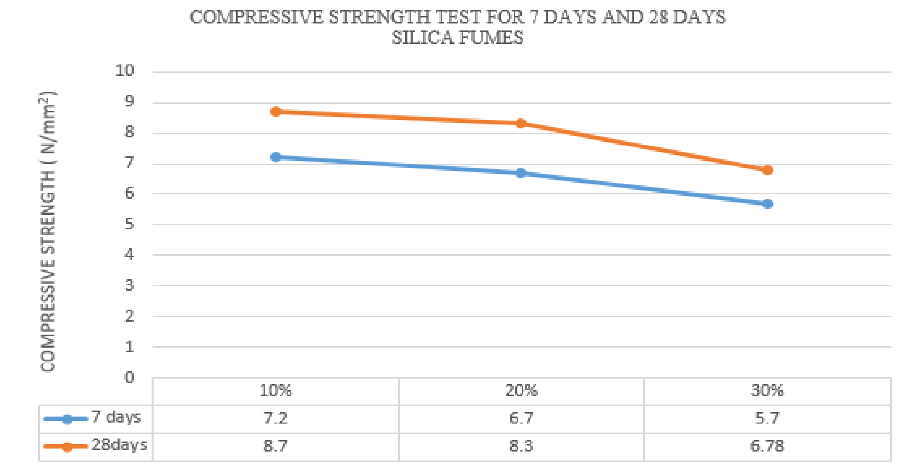
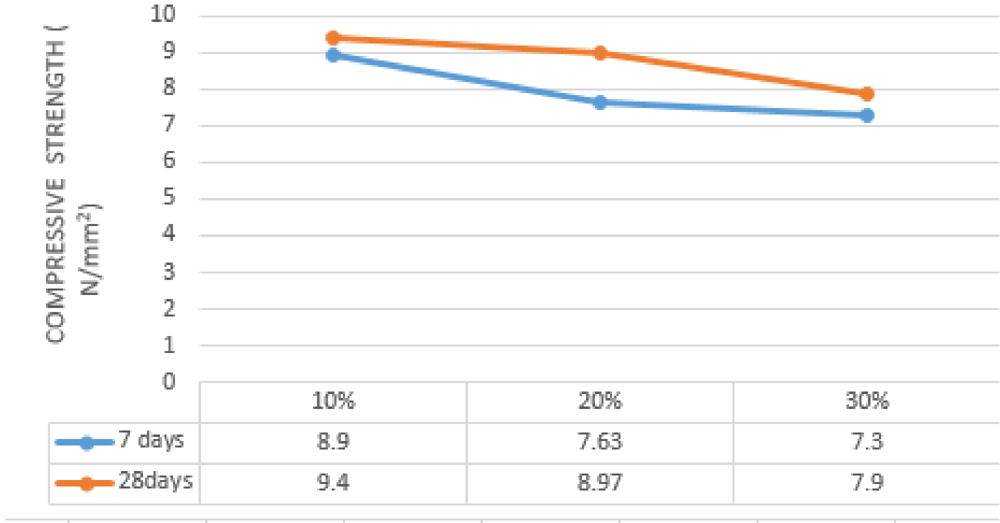


Figure 2 Compressive Strength for Silica Fume Replacement

The compressive strength for silica fumes showed a lower compressive strength as compared to fly ash. In figure 2 the strength for 10% replacement of cement by silica fumes, the compressive strength for 7 days curing period was 7.2 N/mm^2 and this increased to 8.7N/mm^2. The strength however reduced to 5.7 N/mm^2 for 30% replacement of cement by fly ash. The strength for 10% replacement showed an increase in strength by 20.83%. The increase in strength for 30% replacement was observed as 18.94%.

Compressive strength on Ceramic waste concrete



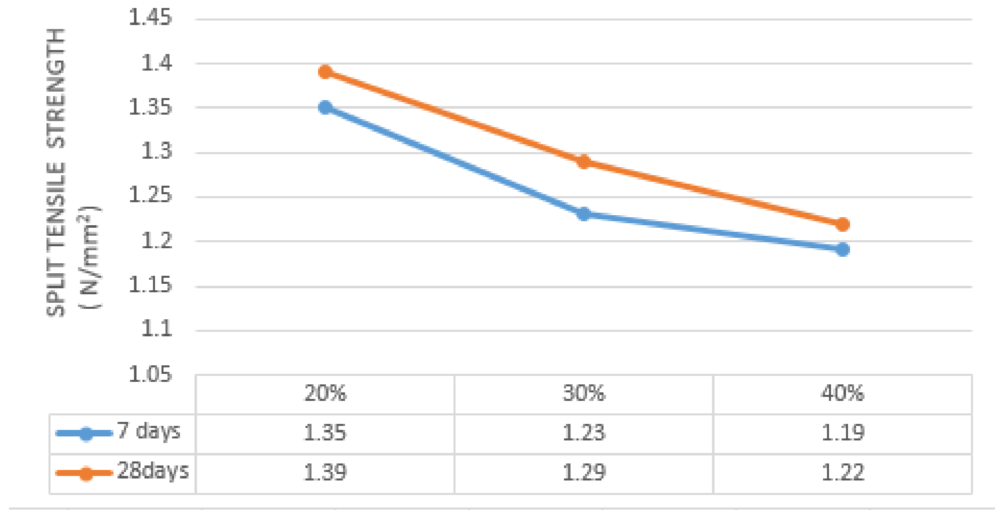
	10%	20%	30%
7 days	8.9	7.63	7.3
28days	9.4	8.97	7.9

Figure 3 Compressive strength for Ceramic Waste Replacement

In figure 3, the compressive strength for replacement of coarse aggregate by ceramic waste for 10% replacement of coarse aggregate by ceramic waste showed a good compressive strength for curing period of 7 days and 28 days as well. But the strength was marginal for 10% replacement. The strength showed a marginal increase of 5.617% increase in strength for 10% replacement for curing period of 7days and 28days. The strength however increased by 17.56 % for 20% replacement for 7 days and 28 days curing period. The strength for 30% replacement for 7days curing period was 7.3 N/mm^2 and it showed a very marginal increase in strength for 28 days curing period.

Split Tensile Strength

Split Tensile strength for fly ash concrete



	20%	30%	40%
7 days	1.35	1.23	1.19
28days	1.39	1.29	1.22

Figure 4. Split Tensile Strength for Fly Ash replacement

In figure 4 the split tensile strength for fly ash is 1.35 N/mm^2 and the strength reduces with increase in the percentage of replacement of cement by fly ash. For 28 days curing period and 20% replacement,the split tensile strength is 1.39 N/mm^2 . The increase in split tensile strength is only 2.96 %. The strength for 40 % replacement is 1.19 N/mm^2 . The strength increases by 2.52% for 28 days curing period and 40 % replacement.

Split Tensile Strength for Silica Fume concrete

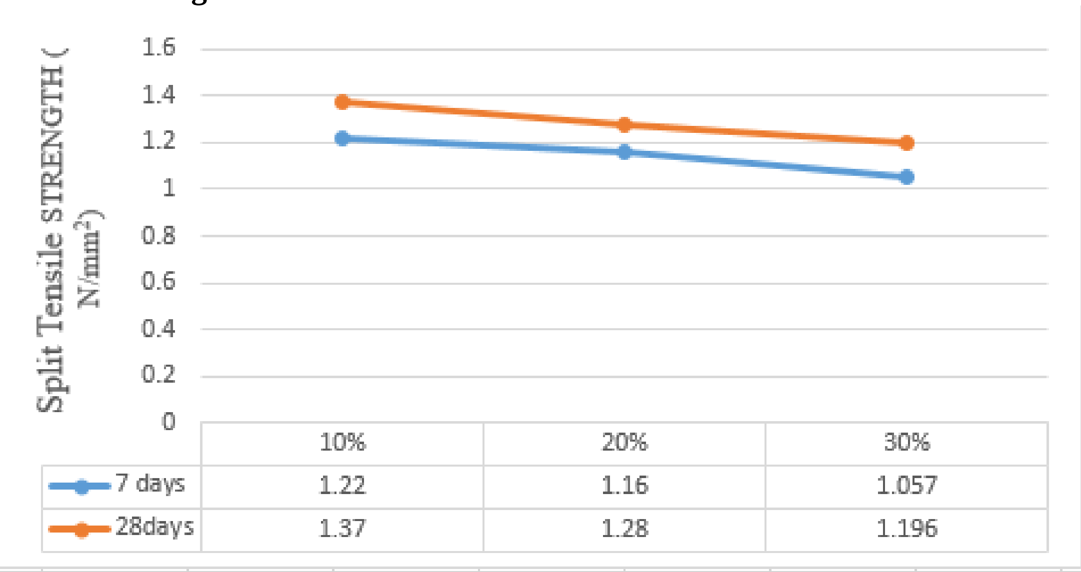


Figure 5 Split Tensile Strength for Silica Fume replacement

In figure 5, the strength for 10% replacement and 7 days curing period, the split tensile strength is 1.22 N/mm^2. This strength, however, increases to 1.37 N/mm^2 .The strength decreases for 20% replacement and further reduces at 30% replacement. However, for every replacement, the strength increases marginally for 28 days curing period.

Split Tensile Strength for Ceramic Waste concrete

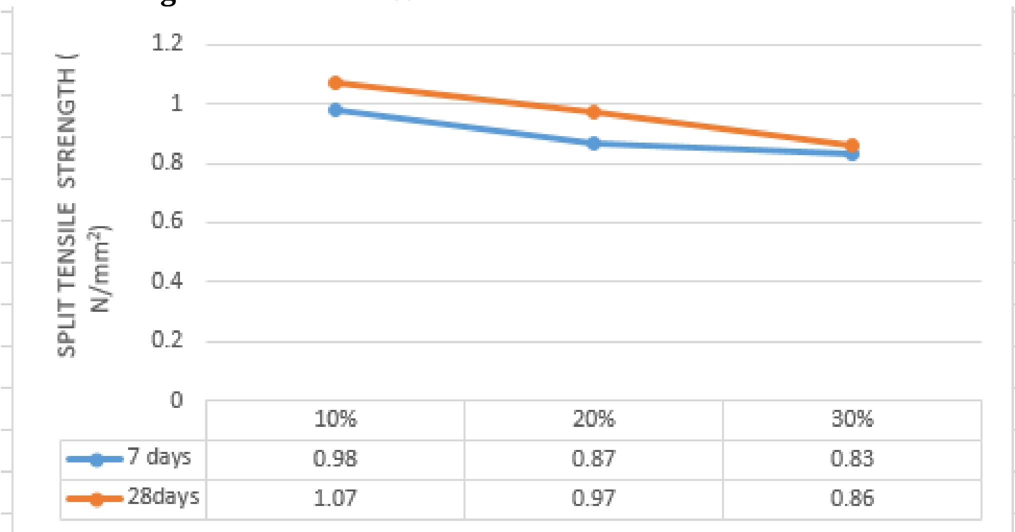


Figure 6 Split Tensile Strength for Ceramic Waste replacement

In figure 6, the split tensile strength for 10% replacement and 7 days curing period is 0.98 N/mm^2 and this strength gets increased by only 9.18% to 1.07 N/mm^2 for 28 days curing period. There is a significant increase in strength for 20% replacement but for 30% replacement, there is a negligible increase in strength between 7 days and 28 days curing period.

Flexural Strength Test

Flexural Strength for Fly Ash concrete

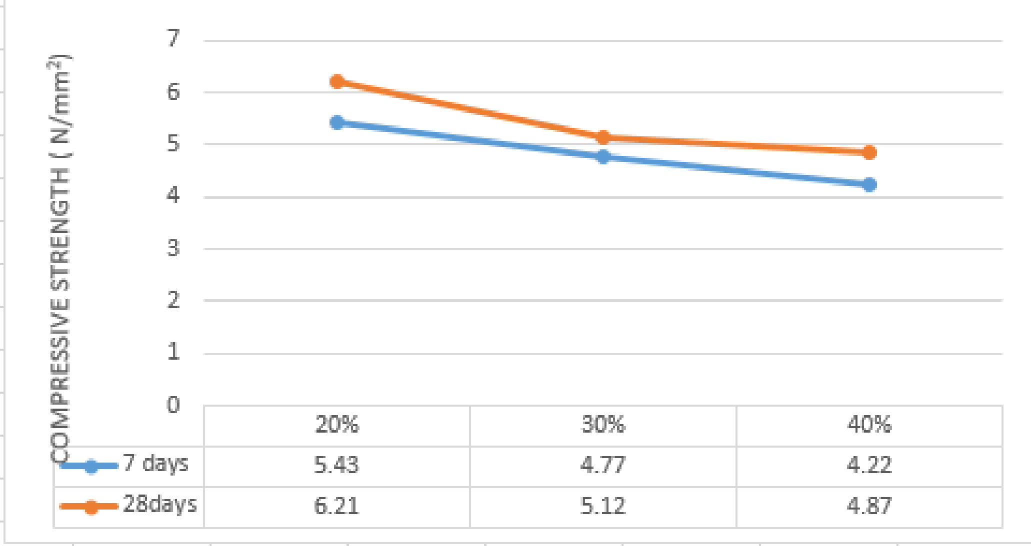


Figure 7 Flexural Strength for Fly ash Replacement

In figure 7, the strength for 20% fly ash replacement for 7 days curing period is 5.43 N/mm2 and this strength increases to 6.21 N/mm2 for 28 days curing period. The strength, however, decreases to 4.22 N/mm2 for 40% replacement and 7 days curing period. There is not much significant increase in strength for 40% replacement for 28 days curing period.

Flexural Strength for Silica fume concrete

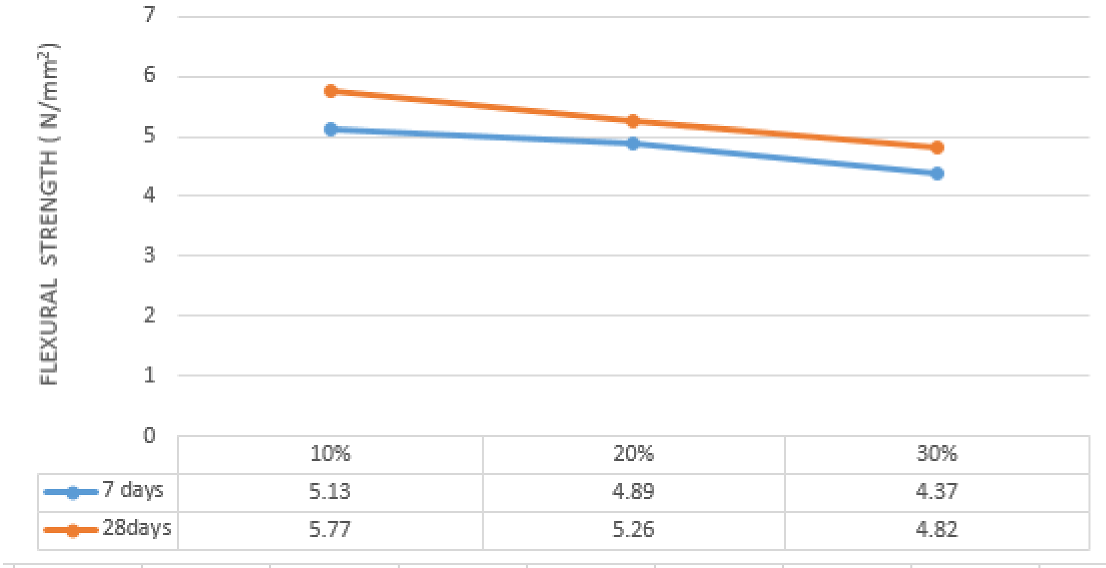


Figure 8 Flexural Strength for Silica Fume Replacement

In figure 8, the strength for 10% replacement and 7 days curing period is 5.13 N/mm^2 and this strength increases by 12.47% for 28 days curing period. From figure 8 we can see that for 20% replacement there is very less increase in strength between 7 days and 28 days curing period. The value for 30% replacement shows a decrease in strength as compared to 10% replacement or 20% replacement.

Flexural Strength for Ceramic Waste concrete

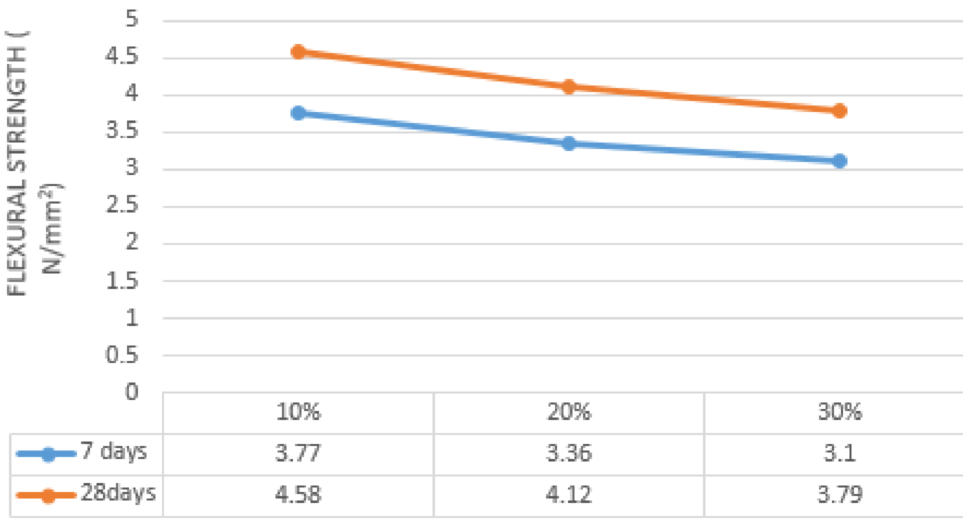


Figure 9 Flexural Strength for Ceramic Waste Replacement

In figure 9, the flexural strength for 10 replacement of coarse aggregate by ceramic waste is 3.77 N/mm^2 and this value is very less in comparison to fly ash replacement or silica fume replacement. The strength decreases with an increase in the replacement of coarse aggregate by ceramic waste. The strength is 3.1 N/mm^2 for 30% replacement and 7 days curing period. However, this strength increases when there is an increase in curing period.

CONCLUSION

1) The compressive strength of 20%, 30% and 40% of cement replaced by fly ash reduced by 19.07%, 28.91%, and 37.10% respectively for 7 days curing period. The compressive strength of 20%, 30%, and 40% of cement replaced by fly ash reduced by 16.64%, 31.27%, and45.36% respectively for 28 days curing period.

2) The compressive strength of 10%, 20% and 30% of cement replaced by silica fumes reduced by 20.21%, 23.95% and 32.03% respectively for 7 days curing period. The compressive strength of 10%, 20% and 30% of cement replaced by silica fume reduced by 14.89%, 22.41%, and 28.91% respectively for 28 days curing period.

3) The compressive strength of 10%, 20% and 30% of coarse aggregate replaced by ceramic waste reduced by 27.63%, 35.50%, and 40.49% respectively for 7 days curing period. The compressive strength of 10%, 20% and 30% of coarse aggregate replaced by ceramic waste reduced by 29.53%, 36.61%, and 41.69% respectively for 28 days curing period.

4) The split tensile strength of 20%, 30% and 40% of cement replaced by fly ash reduced by 36.91%, 42.52% and 44.39% respectively for 7 days curing period. The split tensile strength of 20%, 30% and 40% of cement replaced by fly ash reduced by 50.71%, 53.59% and 56.11% respectively for 28 days curing period.

5) The split tensile strength of 10%, 20% and 30% of cement replaced by silica fumes reduced by 42.45%, 45.28% and 50.47% respectively for 7 days curing period. The split tensile strength of 10%, 20% and 30% of cement replaced by fly ash reduced by 52.92%, 56.01% and 58.90% respectively for 28 days curing period.
6) The split tensile strength of 10%, 20% and 30% of coarse aggregate replaced by ceramic waste reduced by 43.67%, 50% and 52.29% respectively for 7 days curing period. The split tensile strength of 10%, 20% and 30% of coarse aggregate replaced by ceramic waste reduced by 53.67%, 58.0% and 62.77% respectively for 28 days curing period.
7) The flexural strength for 20%, 30% and 40% of cement replaced by fly ash reduced by 19.07%, 28.91% and 37.10% for 7 days curing period. The flexural strength for 20%, 30% and 40% of cement replaced by fly ash reduced by 16.64%, 31.27% and 45.37% respectively for 28 days curing period.
8) The flexural strength for 10%, 20% and 30% of cement replaced by silica fumes reduced by 20.21%, 23.95% and 32.03% for 7 days curing period. The flexural strength for 10%, 20% and 30% of cement replaced by silica fumes reduced by 14.89%, 22.41% and 28.90% respectively for 28 days curing period.
9) The flexural strength for 10%, 20% and 30% of coarse aggregate replaced by silica fumes reduced by 27.63%, 35.50% and 40.49% for 7 days curing period. The flexural strength for 10%, 20% and 30% of cement replaced by fly ash reduced by 29.53%, 36.61% and 41.70% respectively for 28 days curing period.
10) The rate of absorption was lowest for ceramic waste replacement. 40% fly ash concrete and 30 % silica fume concrete showed a somewhat similar value for the water absorption rate.
11) The use of recycled waste not only enhanced the property of concrete but also reduced the cost of concrete as compared to conventional concrete.

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