Experimental Investigation on Geopolymer Concrete with Partial Replacement of Coarse Aggregate Using CTW

Joseph David Selvan.M[1], Sahaya Sofia.A[2]
[1]Assistant Professor, [2]PG Student
[1]Department of Civil Engineerring, [2]Structural Engineering
St. Xavier's Catholic College of Engineering,
Chunkankadai, Tamil Nadu, India.

Abstract—**The ceramic industry is known to generate large amount of calcined-clay wastes each year. So far a huge part is used in landfills. Reusing these wastes in concrete could be a well-balanced solution. It will lead to avoid the environmental problems related to land filled wastes. Concrete is the most used material, which required large quantities of Portland cement. Ordinary Portland cement production is the major generator of CO2 which polluted the atmosphere. Hence it is inevitable to find an alternative material. Fly ash is a byproduct of coal obtained from the thermal power plant, which is an excellent alternative construction material to the existing plain cement concrete. Geopolymer concrete shall be produced without using any amount of ordinary Portland cement. This study aims at reviewing the part research work on the use of ceramic waste aggregate as possible partial substitute for conventional coarse aggregate in geopolymer concrete. The main objectives of this paper is to experimentally investigate the strength and durability of the geopolymer concrete by partially replacing coarse aggregate using ceramic tile waste (CTW) with optimum alkaline activator. Results showed that the compressive strength splitting tensile strength and flexural strength increased while replacing coarse aggregate by CTW up to 20%. The results revealed that the geopolymer concrete without CTW has higher durability property than the geopolymer concrete with CTW.**

Keywords- Geopolymer, ceramic tile waste, alkaline activator, durability, mechanical strength.

I. INTRODUCTION

Geopolymers are relatively new materials, which were first developed by Joseph Davidovits and patented in the 70s [1]. The mechanism involves the polymeric reactions of silica and alumina, liberated by alkali- activating solutions (mainly hydroxides, and silicates of potassium and sodium) from the source material, in the presence of high temperature. Out of various industrial by-products, fly ash can be considered as most beneficial due to its suitable chemical composition, fine size and easy availability [10]. The increase in the reactivity of the fly ash is attributed to the increase of the exposure area between the fly ash particles and the alkali activator [3]. As the world population increases so does the demand for housing. Thus, in pursuit of a sustainable solution, more attention are channeled towards using wastes and local materials for construction. Ceramic wastes from production and those sourced from construction and demolition have been considered as a partial replacement for conventional aggregates [7]. From the previous studies it was found that, the mechanical performance of the CWA concretes was better than that of the control concrete [2]. Derrick et al have shown that the compressive strength of the floor and wall tile increased up to 50% replacement [25]. It is advisable to replace coarse aggregate by CTW in concrete up to 30% for structural purpose [4]. The use of crushed brick and tile aggregates reduced the overall unit weight of the concrete and improves the thermal and acoustic properties [5]. S. Ushaa et al have studied the effects of different parameters on the geopolymer binder [6]. A. Pacheco-Torgal et al have studied the strength and durability characteristics of ceramic wastes based concrete [8]. Properties of ceramic sanitary ware waste do not depart from properties of traditional natural aggregate, and therefore it may be used as concrete aggregate [9]. The presence of calcium was found to be most significant factor in controlling the compressive strength of geopolymer concrete [10]. Concrete made with up to 20% of recycled coarse mixed aggregates achieved similar compressive strength to that of high performance conventional concreteof100 MPa [13]. Zengqing Sun et al have studied the thermal and mechanical behaviour of geopolymer type material from waste ceramic [15]. The SEM observations showed that smaller particle size distributions densified the microstructure and enhanced the geopolymerization process [16]. Geopolymer concrete can be a practical alternative to OPC concrete in reinforced concrete structures when fire resistance is one of the main design considerations [17]. SajjadYousefiOderji et al have studied the mechanical and microstructural properties of alkali-activated fly ash based geopolymers cured at various RH ratios at 75^0C [18]. The ductility of the geopolymer concrete reduces rapidly with increase in temperature [20]. A. Fenghong Fan et al have studied the mechanical and thermal properties of fly ash based geopolymers [21]. The increase of NaOH molarity from 10 M to 16 M improves 7- day compressive and flexural strengths for all binders[22].

Hence, the purpose of this study is to findout the optimum replacement of ceramic tile in geopolymer concrete and to study the strength and durability characteristics of geopolymer concrete by adding ceramic tile waste (CTW).

II. MATERIALS ANDMETHODS

2.1. Materials:

Class F Fly ash obtained from local sources, were used in this study. The Fineness of fly ash particles was 13% and specific gravity was determined as 2.04. Crushed stone aggregates of nominal diameter 12.5 mm were used as coarse aggregates with specific gravity 2.68, Bulk density 1800 kg/m^3, Natural moisture content 0.1%, Impact value 14.13%, Elongation index 5.24%, Flakiness index 24.6% and water absorption 1.13% whereas, natural river sand was used as fine aggregates with fineness modulus 3.8, specific gravity 2.69, Bulk density 1600 kg/m^3, Natural moisture content 0.67%, and water absorption 2.3%. The ceramic tile wastes used in this study was obtained from local market and it was crushed to a size of 12.5mm using hammer which having Specific gravity 2.24, Fineness modulus 7.085, Water absorption 2.1%, Bulk density 1550kg/m^3, Natural moisture content 0%, Impact value 20.46%, Elongation index 5.2% and Flakiness index of 21.68%. The alkali-activating solution was prepared as the mixture of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). The NaOH solution was prepared by mixing NaOH pellets and the distilled water with desired molarity whereas Na_2SiO_3 solution was obtained from local market. Due to the high temperature of the alkali-activating solution, it was prepared 24 h prior to its use to bring down its temperature to ambient conditions

2.2. Optimum Mixture Determination:

Trial mixes was made to determine the optimum parametric combination to yield maximum compressive strength. four factors were expected to influence the strength characteristics of fly ash based geopolymerconcrete such as ratio between Na_2SiO_3: NaOH, alkaline to fly ash ratio, NaOH molarity, and curing temperature for the constant duration. these parameters such as 2, 2.5, 3 ratio between Na_2SiO_3: NaOH; 0.3, 0.35, 0.4, 0.6, 0.8 alkaline to fly ash ratio; 12, 14 & 16 M NaOH molarity, and 65 & 75^{0}C curing temperature were considered. Factors such as aggregates content, and curing duration (48 h) were kept as constant after performing various trial mixtures, the final design mixture was adopted as concentration of NaOH is 16m, alkaline to flyash ratio is 0.6, na_2sio_3: naoh ratio is 2.5, oven curing temperature is75^{0}c.

2.3. Methods:

Geopolymer concrete specimens were prepared by mixing fly ash, coarse aggregates and fine aggregates together with the alkali-activating solution, which was prepared 24 h before casting. The details of the mix proportion of the geopolymer concrete are given in table.

The materials were mixed inside a pan mixture for about 15 min and the concrete was filled in the specimens with proper compaction. For compressive strength, cube molds of size 100 x 100 x 100 mm, for spilt tensile strength, the cylindrical mold of size 100 mm diameter and 200 mm length and for flexural strength prism of size100 x 100 x 500 mm were cast. The specimens were kept at room temperature for about 24 hours. These specimens were subjected to oven curing for 48h. The de-molded specimens after curing were kept at room temperature until its testing age. For compressive strength testing, spilt tensile strength testing and flexural strength testing the cubical, cylindrical and prism concrete specimens were kept inside the appropriate testing machines at the age of 7 days. The load was applied to the specimens as shown in Fig 1,2,3 without any jerk until no further load was sustained. Table 2 shows the compression, spilt tensile and flexural strength of geopolymer concrete with different % of CTW. For durability test the cubical specimen of size 100 x 100 x 100 mm were immersed into the appropriate solutions as shown in Fig 4 for a period of 90 days and for water absorption test, the specimens were dried in an oven at a temperature of 110^{0}C for 24 h to ensure that a constant mass was achieved. The specimens were left at a room temperature to obtain their initial weight they were then immersed in water for four days to measure their saturated weight. Water absorption was then quantified by the change in weight as a percentage of the initial weight [14]. Table 3 and 4 shows the durability property of geopolymer concrete with different % of CTW. These specimens were tested for each mixture and the results were reported as their average.

III. RESULT AND DISCUSSION

3.1 Mechanical Properties:

The compressive strength results obtained are in close range with those obtained in previous researches where the influence of ceramic wastes aggregate on compressive strength have been evaluated and it was found that compressive strength remained constant compared with the reference concrete in all cases. Compression test results are presented in Table 1 for the replacement of coarse aggregate by CTW from 0% to 50%. Present study has shown that concrete with 20% ceramic coarse aggregate replacement yielded higher strength than the control mix. The aggregate replacement proportion had little effect on the compressive strength of the specimens, with a maximum strength decrease of 16% in the 50% tile replacement specimens, compared to the reference concrete shown in chart 1. The minimal change in strength at even 50% replacement shows that ceramic is a viable aggregate replacement source.

Fig 1: CompressionTest

Fig2: Split TensileTest

Fig 3: FlexuralStrengthTest

Fig 4: DurabilityTest

Table 1: Details of mix proportion of the geopolymer concrete

Mix no	Fly ash (Kg/m^3)	Sand (Kg/m3)	Coarse aggregate (Kg/m^3)	CTW (Kg/m^3)	NaOH (Kg/m^3)	Na2Sio3 (Kg/m^3)
M (0%)	375	540	1260	0	64.28	160.72
M (10%)	375	540	1134	126	64.28	160.72
M3 (20%)	375	540	1008	252	64.28	160.72
M4 (30%)	375	540	882	378	64.28	160.72
M5(40%)	375	540	756	504	64.28	160.72
M6(50%)	375	540	630	630	64.28	160.72

Table 2**:** Results of mechanical properties testing

Mix no	Compressive strength (MPa)	Tensile strength (MPa)	Flexural strength (MPa)
M (0%)	27.8	2.96	5.00
M3 (10%)	29.3	3.07	5.67
M4 (20%)	32.8	3.23	6.08
M (30%)	30.17	2.97	5.33
M3 (40%)	26.67	2.55	4.58
M6 (50%)	23.3	2.12	4.17

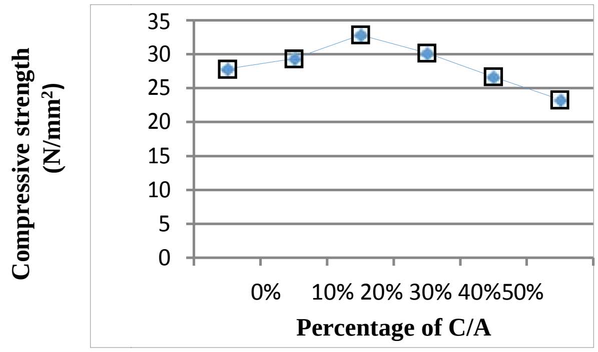

Chart 1**:** Compressive strength for different % of CTW

The tensile strength was tested using 100 x 200 mm cylinders tested in split tension in a 3000 kN compression machine, and the results of the replacement series are presented in Chart 2.

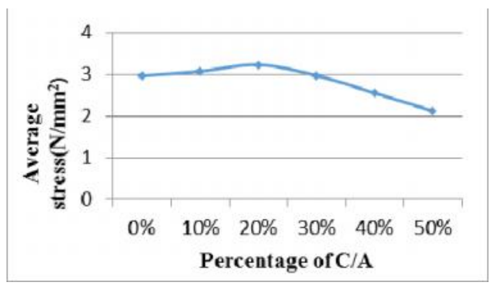

Chart 2: split tensile strength for different % of CTW

The aggregate replacement proportion had little effect on the compressive strength of the specimens, with a maximum strength decrease of 25% in the 50% tile replacement specimens, compared to the reference concrete.The flexural strength was tested using 500 x 100 x 100 mm prisms tested with two point bending setup and the results of the replacement series are shown in Chart 3.

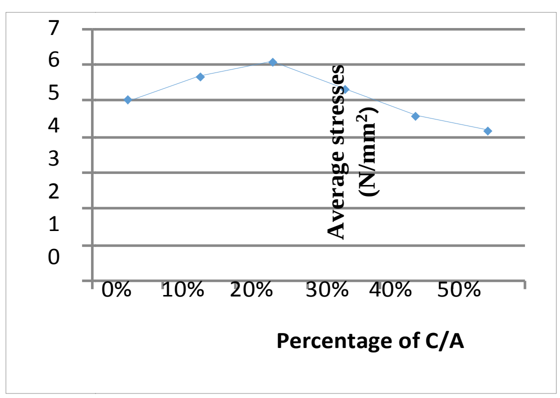

Chart 3: Flexural Strength for different % of CTW

The flexural tests were the first to exhibit a marked difference with the increase in aggregate replacement, with a gradual decrease and a maximum decrease of 16.6% with tile 50% replacement series compared to the reference concrete.

3.2. Durability properties:

The water absorption and ultrasonic pulse velocity test were tested using 100 x 100 x 100 mm cubessThe results of water absorption and ultrasonic pulse velocity test are given in table 3.

Table 3: Results of durability properties testing

Mix no	Water absorbtion(%)	Ultrasonic pulse velocity (m/s)
M(0%)	2.3	3950
M3 (10%)	2.63	3880
M4(20%)	3.0	3830
M(30%)	3.24	3550
M3(40%)	3.6	3060
M6(50%)	4.1	2950

While increasing the % of CTW in geopolymer concrete this leads to increase in water absorption. This is mainly due to the porous nature of the tile waste. The measured water absorption showed a maximum 1.8% increase when comparing the 50% replacement specimens to those of the reference concrete shown in chart 4.While increasing the % of CTW in geopolymer concrete which leads to decrease in Ultrasonic pulse velocity which means UV rays takes more time to travel through the concrete specimen. This denotes many obstructions are present inside the specimen like cracks.

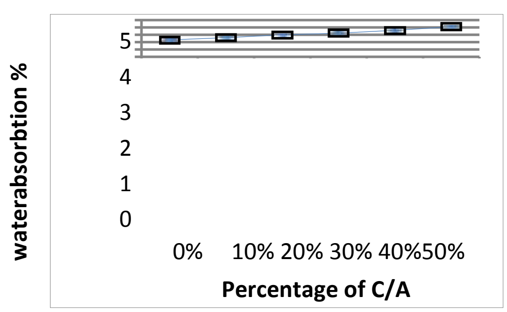

Chart: 4 Water absorption for different % of CTW

The measured Ultrasonic pulse velocity shows a maximum 20% decrease when comparing the 50% replacement specimens to those of the reference concrete shown in chart5. specimens to those of the reference concrete. The measured sulphate attack showed a maximum 1.1% difference in strength when comparing the 50% replacement specimens to those of the reference concrete.

Table 4: Change in wt. due to Sulphate, Chloride and Acid attack

Mix no	% of difference in wt. due to		
	Sulphate Attack	Chloride Attack	Acid attack
M(0%)	0.78	0	0.465
M3 (10%)	0.855	0	0.534
M4(20%)	0.928	0	0.624
M(30%)	0.99	0.078	0.702
M3(40%)	1.085	0.155	0.776
M6 (50%)	1.33	0.156	0.853

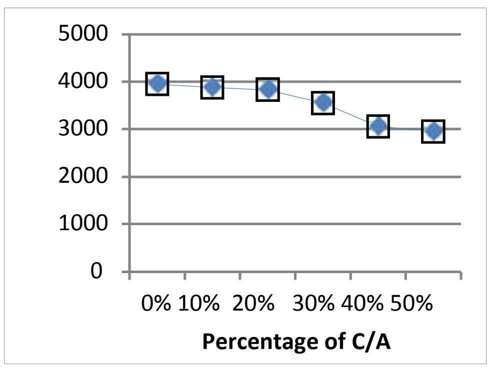

Chart: 5 Ultrasonic pulse velocity for different % of CTW

The Sulphate, Chloride and Acid attack test were tested using 100 x 100 x 100 mm cubessThe results of Sulphate, Chloride and Acid attack test are given in table 4 and table 5. The variation of weight and strength value for different % of CTW due to Sulphate, Chloride and Acid attack are represented in Chart 6 and Chart7.

Table 5: Change in strength due to Sulphate, Chloride and Acid attack

Mix no	% of difference in strength due to		
	Sulphate attack	Chloride attack	Acid attack
M(0%)	0.943	0.11	0.336
M3 (10%)	1.103	0.00	0.345
M4(20%)	1.113	0.103	0.379
M(30%)	1.436	0.221	0.421
M3 (40%)	1.75	0.258	0.475
M6 (50%)	2.04	0.292	0.55

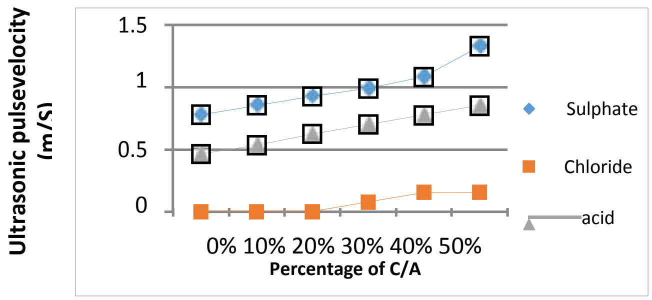

Chart: 6 Wt. variation due to Sulphate, Chloride and Acid attack for different % of CTW

The results of Sulphate attack test showed that there was no significant change in the appearance of the specimens compared to the condition before they were exposed. However, white patches were observed on the specimens. There was no sign of surface erosion, cracking or spalling on the specimens. The measured Sulphate attack showed a maximum 0.3% difference in weight when comparing the 50%replacement.

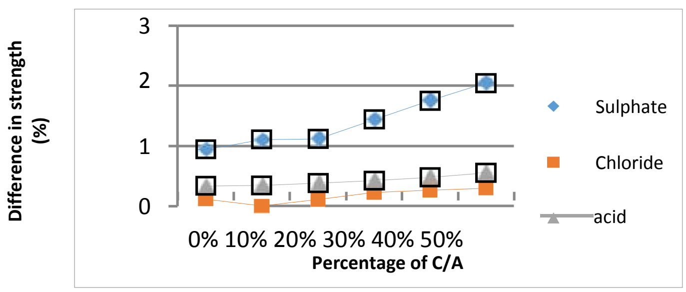

Chart: 7 Strength variation due to Sulphate, Chloride and Acid attack for different % of CTW

The results of Acid attack test showed that there were no reductions in mass and visual appearance were observed. There was no major change in compressive strength, only slight reduction in compressive strength took place. The measured Chloride attack showed a maximum 0.156% difference in weight when comparing the 50% replacement specimens to those of the reference concrete. The measured Chloride attack showed a maximum 0.29% difference in weight when comparing the 50% replacement specimens to those of the reference concrete.

IV. CONCLUSION

This paper has presented the results of an experimental study that was undertaken to investigate the strength and durability property of geopolymer concretes while partially replacing coarse aggregate by CTW. The following conclusions can be drawn based on the results and discussions reported in this paper:

1. Compressive strength is increases while increasing the concentration of NaOH from 12 to16
2. Compressive strength and workability are increases while increasing the alkaline to flyash ratio from 0.3 to 0.6 and it starts to decrease beyond 0.6
3. Compressive strength is increases while increasing the ratio between Na_2Sio_3: NaOH from 2 to 2.5 and it starts to decrease from3
4. Compressive strength is increases while decreasing the quantity of water to be added in themix
5. Oven curing at 75^0c for 24hrs is found to be good for better compressive strength and it starts to decreases while increasing the temperature from 75^0c to85^0c.
6. It is advisable to replace coarse aggregate by CTW in geopolymer concrete upto 20% for structuralpurpose.
7. Further researches are needed to enhance the durability property of geopolymer concretes while replacing coarse aggregate by CTW.

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