

Utilizing rice husk ash as a bio-waste material in geopolymer composites with aluminium oxide

Thirukumaran T.^{1*}, Krishnapriya S.¹, Priya V.², Sagai Francis Britto A.³, Anandhalakshmi R.¹, Dinesh S.¹, Poomalai R.⁴, Vivek S.^{2*} and Saravanan S⁵

¹Department of Civil Engineering, AAA College of Engineering and Technology, Sivakasi, Educational Road, Amathur, Sivakasi-626123, India

²Department of Civil Engineering, GMR Institute of Technology, Razam-532127, India

³Department of Mechanical Engineering, Rohini College of Engineering and Technology, Palkulam-629401, India

⁴Department of Civil Engineering, Hindusthan College of Engineering & Technology, Coimbatore-641032, India

⁵Department of Civil Engineering, National Institute of Technology, Trichy-620015, India

Received: 25/12/2022, Accepted: 24/04/2023, Available online: 02/05/2023

*to whom all correspondence should be addressed: e-mail: civilthirukumaran@gmail.com

https://doi.org/10.30955/gnj.004694

Graphical abstract



Abstract

Permanent damages and spalling occur in conventional concrete due to hightemperature. Also concrete loses its compressive strength amounting to about 50 to 75% of the original strength as reported in most of the research works. As opting for high grade of concrete leads to higher costs and emits CO₂, an attempt to developthermal resistant geopolymer concrete is done. A new class of silica-alumina binders called geopolymers has the ability to withstand high temperatures. Generally geopolymer concrete (GPC) is having good strength and durability

properties. In this paper, the heat resistance and strength performance of geopolymeris improved by adding aluminium oxide as admixture in the doses of 1% and 2% byweight of rice husk ash. With rice husk ash, fine aggregate and coarse aggregate, thermally resistant GPC was created. As alkali activators, sodium hydroxide and silicate were employed. The molarity of NaOH solution was 12 and 14. The specimens were cast and ovencured at 60°C for 24 hours. The specimens were tested to determine strength, permeability, durability and thermal studies of geopolymer concrete.

Keywords: Bio-waste (rice husk ash), compressive strength, CO₂, silica-alumina binders, thermal resistant, geopolymer concrete

1. Introduction

Flame retardants are used in building materials and products to meet important fire safety standards and codes. According to reports, one of the most significant fire-resistant building materials is geopolymer concrete. Materials that are fire resistant have the capacity to sustain high temperatures without being destroyed. Due to its amorphous and ceramic-like characteristics, geopolymer cement has a potential for enhanced fire resistance. The more porous structure of the geopolymer concrete specimen makes it easier for the internal steam pressure to be released during heating. As a result, the geopolymer concrete undergoes less tensile stress and becomes more fire resistant. Geopolymers, in particular Ca (OH) 2, lack the hydrate phase. When Portland cement is exposed to high temperatures (>400°C), internal tensions are caused by structural water. The Ca (OH)2 dehydroxilate to CaO process also CaO rehydrates with a volume change when it cools on its own, damaging matrices in the process. On the other hand, geopolymers re-crystallize into more heat-resistant anhydrous aluminosilicate solids. Geopolymers based on rice husk ash are

Thirukumaran T., Krishnapriya S., Priya V., Britto F.S., Anandhalakshmi R., Dinesh S., Poomalai R., Vivek S. and Saravanan S. (2023), Utilizing rice husk ash as a bio-waste material in geopolymer composites with aluminium oxide, *Global NEST Journal*, **25**(6), 119-129.

considered in this section. One of the most chemically stable oxides known, aluminium oxide has a melting point of 2070°C and exceptional hardness, strength, and spalling resistance. In this project aluminium oxide was as an additive. The final objective of this study, comparision between the mechanical properties and the residual compressive strength at elevated temperature of Thermal Resistant GeopolymerConcrete (TRGPC). Also, to conduct the permeability and durability tests on Geopolymer concrete and study their effects on the compressive strength of TRGPC.

2. Literature review

E.P. Ayswarya, Ajalesh B. Nair et al., (2021). In this research, the reinforcement effects of nanosilica (NS), modified rice husk ash (MRHA), and epoxy resin are studied, including the mechanical, dynamic mechanical, and thermal properties of composites. Smaller size and more fillers are needed to improve the characteristics. The mechanical and impact properties of composite are improved by the addition of fillers and an increase in specific surface area. Silica makes up roughly 90% of RHA. As a result, it can be used as a source for making nanosilica. In relation to filler loading, density and specific gravity exhibit an ascending trend. This is because adding fillers with nanoparticle sizes gives the composites a high density. Reduced particle size is what gives NS filled composites their increased tensile strength. Flexural modulus of polymercomposites is dependent on filler nature, and aspect ratio of the filler particles. Enhancement of thermal stability of RHA, MRHA and NS composites is due to the organic/inorganic interaction between the polymer and filler where inorganic filler delays the volatilization of the products generated at the temperature of carbon-carbon bond scission of the polymer matrix.

RattaponSomna, TeeraponSaowapunet al., (2022), This work discusses the use of rice husk ash (RHA) to create hollow geopolymer blocks based on NaOH activation using both rice husk ash and fly ash (FA). For 15, 30, 60, and 90 minutes, RHA was grounded. Using 14 molar sodium hydroxide, the RHA to FA ratios of 10:90, 20:80, 30:70, 40:60, and 50:50 by weight were applied. At 7, 28, and 60 days, the compressive strengths of geopolymer paste were evaluated. The geopolymer blocks' compressive strengths and water absorption rates were evaluated after 7 and 28 days. The findings demonstrated that the geopolymer's compressive strength rose as RHA content did. Amorphous silica was present in the RHA, which also improved strength and the SiO2/Al₂O₃ ratio. With an increase in RHA fineness, geopolymer's compressive strength rose. The carbon footprint of a geopolymer hollow block made of rice husk ash and fly ash was roughly two thirds that of a Portland cement system. The outcome demonstrates that the rice husk ash and fly ash geopolymer hollow block could be employed while maintaining standard compressive strength and water absorption. Geopolymer hollow blocks manufactured from rice husk and fly ash have a lower carbon footprint than cement-based ones. As a result, the community and

environment benefit from this product's use of environmentally friendly materials.

Herwani, Ivindra Pane et al. (2018), the purpose of this study was to determine the impact of alkaline activator solution (AAS) molarity on the compressive strength of geopolymer concrete made from fly ash with a variable sodium hydroxide (NaOH) solution molarity. As a test variable, sodium hydroxide solution was selected as the activator solution. The sodium hydroxide solution concentrations utilised for ambient curing were 10M, 12M, and 14M. According to test results, raising the content of sodium hydroxide (NaOH) solution increases the compressive strength of geopolymer concrete. Geopolymer concrete's ideal compressive strength was attained at a sodium hydroxide solution (NaOH) concentration of 12M. Geopolymer concretes compressive strength only achieves around 50-60% of the planned. On a 12M molar NaOH solution, geopolymer concrete attained its maximum compressive strength. Only 50–60% of the required compressive strength was really reached. The geopolymer concrete shrank the least when the NaOH solution had a 14M molarity. On a molarity of 12M, the compressive strength increased by 32.56% the most, whereas on a molarity of 14M, it increased by just 8.51%. The geopolymer concrete also demonstrated a high initial compressive strength.

3. Materials investigation

All the constituent materials used in this research work and their properties are stated below.

3.1. Rice husk ash

Rice husk ash also improves concrete permeability through lowering the water-to-cement ratio, which reduces the volume of remaining capillary pores in the mass. Rice husk ash's spherical shape improves concrete consolidation even while reducing permeability. The rice husk ash emerged from agricultural waste in India.

3.2. Fine aggregate

Fine aggregate (river sand) used in this study was passing through 4.75 mm IS sieve, conforming to grading zone-I of IS 383 - 1997. The specific gravity of the fine aggregate was 2.6.

3.3. Coarse aggregate

Gravel particles that passed a 16 mm sieve, were retained on a 12.5 mm sieve, and were retained on a 10mm sieve were used as coarse aggregate in concrete production in accordance with IS 383 - 1997. The coarse aggregate had a specific gravity of 2.9. The coarse aggregate was washed and used to improve workability.

3.4. Alkaline solution

The alkaline solution as a binding material was a mixture of sodium hydroxide and sodium silicate. We used commercial grade sodium hydroxide pellets (97% - 100% purity) and sodium silicate solution with a composition of 14.7% Na2O, 29.4% SiO2 (total solids = 45.4%) and 55.6% water by mass. The alkaline solution is used to activate silica and alumina for improving bond and involves polymerization process. After several experiments with

conformance to workability and strength, the alkaline liquid to binder ratio was determined at 0.4 and the sodium silicate to sodium hydroxide ratio was set at 1:1. The preliminary survey has been conducted using various molarities. The sodiumhydroxide content was fixed at 12 M and 14 M for all tests, and two different NaOH concentrations were used.

3.5. Aluminium oxide powder

Aluminium oxide, often known as Al_2O_3 , is a chemical compound composed of aluminium and oxygen. It is the most frequent of numerous aluminium oxides and has been designated as aluminium (III) oxide. It is widely

recognized as alumina, however it can also be referred to as aloxide, aloxite, or alundum depending on its form or application. Because of its high melting point, Al_2O_3 is crucial in the production of aluminium metal and as a refractory material. Although Al_2O_3 is an electrical insulator, it has a reasonably high thermal conductivity for a ceramic material (30Wm-1K-1). Water does not dissolve aluminium oxide. Aluminium oxide is important for metallic aluminum's resistance to weathering. It has a density of 3.95g/cm3. It has a boiling point of $5391^{\circ}F$ (2977°C) and a melting point of $3762^{\circ}F$ (2072°C).

		12 Molarity			14 Molarity	
Materials	Without Al ₂ O ₃ Kg/m ³	With 1% of Al₂O₃ Kg/m³	With 2% of Al ₂ O ₃ Kg/m3	Without Al₂O₃ Kg/m3	With 1% of Al₂O₃ Kg/m3	With 2% of Al₂O₃ Kg/m³
Rice husk ash	394.29	394.29	394.29	394.29	394.29	394.29
Fine aggregate	554.4	554.4	554.4	554.4	554.4	554.4
Coarse aggregate	1293.6	1293.6	1293.6	1293.6	1293.6	1293.6
Sodium hydroxide solution	78.857	78.857	78.857	78.857	78.857	78.857
Sodium silicate	78.857	78.857	78.857	78.857	78.857	78.857
Aluminium oxide	-	3.943	7.886	-	3.943	7.886

4. Mix proportion and casting

4.1. Mix proportion

4.2. Preparation of test specimens and casting

The constituents for the mixes were weighed and blended for 3-4 minutes in dry environment. To enhance workability, the coarse aggregate was rinsed in tap water and filtered. The needed alkaline activator solution, a combination of sodium hydroxide and sodium silicate solutions, as well as aluminium oxide, is then added to the dry mix. In a concrete mixture machine, the mixing was maintained for around 6-8 minutes. Following the mixing, the concrete was poured in steel moulds with suitable compaction. Precautions were made to ensure that the ingredients were mixed evenly. The casted specimens healed in two days under the warm conditions depicted in Figure 1. The geopolymer concrete are used to cure in sun light, steam and oven. The specimens were de-moulded and placed in a 60°C oven curing for 24 hours shown in Figure 2. Then they were taken out shown in Figure 3 and allowed to cure in the room temperature till the required day of testing.



Figure 1. Casted Specimens



Figure 2. Oven Curing



Figure 3. Cured Specimens

5. Results and discussion

To test the mechanical and thermal properties of TRGPC produced with Al₂O₃, more than 150 specimens were cast and put through various tests. Tests were performed on TRGPC using two distinct NaOH molarities and three different types of mixtures, including none, 1%, and 2% of Al₂O₃. The findings demonstrate how the percentage of admixture and the concentration of NaOH have an impact on the variation in compressive strength of TRGPC. Additionally, tests were conducted on the GPC specimens' flexural strength and splitting tensile strength. The permeability, durability and thermal studies of TRGPC were evaluated. The differences in the aforementioned parameters of the TRGPC specimen are shown in charts. Below are some discussions of the test findings.

	Table 1.	Results o	n Com	pressive	strength	of TRGP	Ċ
--	----------	-----------	-------	----------	----------	---------	---

5.1. Mechanical properties

5.1.1. Compressive strength

The strength attained during 24 hours oven cured on Geopolymer concrete cubes were experimentally tested for 2 specimens on each average and their average results. The result influences that molarity of sodium hydroxide (NaOH) solution and admixture of Al_2O_3 on the compressive strength of TRGPC was studied for two different molar concentrations of NaOH viz., 12M and 14 M. At 60°C, the oven was used to cure each specimen. The compressive strength results are presented in Table 1, and Figure 4, respectively, show the variations in compressive strength of TRGPC specimens corresponding to the two different molar concentrations of NaOH and% of Al_2O_3 .

SI.No.	NaOH Concentration	Percentage of Al ₂ O ₃	Trial 1(MPa)	Trial 2(MPa)	Average Compressive strength (MPa)
1		-	35.39	31.44	33.42
2	12M	1%	36.73	34.40	35.57
3	_	2%	44.07	44.61	44.34
4		-	38.60	37.06	37.83
5	14M	1%	36.92	37.01	36.97
6		2%	29.23	27.86	28.55



Figure 4. Results on Compressive Strength of TRGPC

The results show that when the concentration of NaOH increased, the compressive strength of TRGPC also increased. The strength increase of the Al_2O_3 -free specimen (GP) after 24 hours in the oven ranged from 5 to 10% for the equivalent rise in molarity starting at 12M and 14M. The increase in compressive strength could have **Table 2.** Results on split tensile strength of TRGPC

been caused by a faster rate of silica and alumina ions dissolving in the alkaline solution due to the rise in NaOH concentration. The 12M-2% of Al_2O_3 gives high compressive strength compared to remaining mixes of specimen. When the 14M - 2% of Al_2O_3 gives low strength because of high molar concentration and increases the percentage of Al_2O_3 might be reduces the strength.

5.1.2. Split tensile strength

The split tensile strength test for the mixes was carried out on cylindrical specimens after 24 hours of curing and their results are presented. The split tensilestrength of the 12M & 14M GPC mixes was noted of 3.355 and 3.457 MPa, and that of adding Al_2O_3 were found to be in the range of 2.595 to 3.506 MPa. The effects of NaOH concentration and % of Al_2O_3 on the split tensile strengthof the TRGPC mixes are discussed in the subsequent table (Table 2 and Figure 5).

Sl.No.	NaOH concentration	Percentage of Al ₂ O ₃	Trial 1(kN)	Trial 2(kN)	Average load (kN)	Average split tensile strength (MPa)
1		-	95.7	115.1	105.40	3.355
2	12M	1%	106.1	114.2	110.15	3.506
3		2%	110.4	109.2	109.80	3.495
4		-	98.7	118.5	108.60	3.457
5	14M	1%	84.1	89.8	86.95	2.778
6		2%	83.4	79.1	81.25	2.595



Figure 5. Results on Split tensile strength of TRGPC

Without adding of Al₂O₃gives promising results compared to research papers. When comparing the 12M - 1% of Al₂O₃mix with 12M - 2% of Al₂O₃there was a slight improvement in split tensile strength. But the split tensile **Table 3.** Results on flexural strength of TRGPC

strength seems to be reduced with additional increases in molar concentration with percentage of Al2O3.

5.1.3. Flexural strength

All of the prism specimens were oven-cured at 60°C, and the flexural strength of the cured specimens was assessed. This circumstance (a 133 mm but > 110 mm for 100mm specimen) results in the breaking point. The findings are listed in Table 3, and Figure 6 displays the variations in compressive strength of TRGPC specimens at the two different molar concentrations of NaOH and% Al₂O₃ respectively. The flexural strength of the 12M & 14M GPC mixes was noted of 4.438MPa and 4.526MPa, and that of adding Al₂O₃ were found to be in the range of 3.447Mpa to 4.579MPa.

Sl.No.	NaOH Concentration	Percentage of Al ₂ O ₃	Trial 1(kN)	Trial 2(kN)	Average load (kN)	Averageflexural strength (MPa)
1		-	37	35	36	4.438
2	12M 	1%	27.5	28	27.75	4.579
3		2%	20	26	23	3.988
4		-	32	39	35.5	4.526
5		1%	29	26	27.5	3.609
6		2%	27	24	25.5	3.447







The variation in the flexural strength of the TRGPC mixes with respect to NaOH concentration. While increasing NaOH concentration increases the flexural strength of the GPC mixes. The improved performance with the increase in the NaOH concentration is primarily because of the increasing amount of leaching of Si and Al at higher concentration of NaOH. In 12M - 1% of Al₂O₃ gives slightly high strength compared to 12M- 2% of Al₂O₃. The rate of decreasing the strength is low in14M mixes compared to 12M mixes.

Sl.No.	NaOHConcentration	Percentage of Al ₂ O ₃	Dried weight (g)	Saturated weight (g)	Percentage of Water absorption
1		-	668.7	686.9	2.72
2	12M	1%	694.2	711.6	2.51
3		2%	691.2	706.5	2.21
4		-	644.7	659.5	2.30
5	14M	1%	730.9	748.7	2.44
6		2%	746.2	767.5	2.85

5.2. Permeability properties

5.2.1. Water absorption

The water absorption after 24 hours of immersion of 14M - 2% of Al₂O₃ specimens was found to be 2.85% and 12M - 2% of Al₂O₃ specimens recorded water absorption of 2.21%. For 12M – without Al₂O₃, it was 2.72% and 14M – without Al₂O₃, recorded a value of 2.30%. This shows the

decrease in water absorption in Geopolymer concrete when the NaOH concentration is high. The water absorption in percentage is shown in Figure 7.

While comparing the 12M and 14M mixes from Table 4 shows that 12M adding the Al_2O_3 gives less absorption because of aluminium oxide able to fills pores and created an additional bond with existing aluminium oxide in GPC. The combination of higher molarity with increasing

percentage of Al_2O_3 might be increases the absorption capacity because of Al_2O_3 is insoluble in water. The presence of higher silica content formed higher quantity of aluminosilicate gel and provides very good particle bonding. Hence, the silicate occupies the void spaces between the Rice husk ash particles resulted in lower water absorption.

5.3. Durability studies

5.3.1. Acid attack

For the purpose of assessing initial corrosion behaviour, the weight and compressive strength losses of TRGPC after exposure to a 5% solution of HCl were measured at 1, 7, and 14 days after immersion. In Table 5 and Figure 8, the weight (actual mass and change in mass) are

 Table 5. Change in mass of TRGPC after exposure of HCI

displayed. The strength variations are depicted in Table 6 and Figures 9 and 10.



Figure 7. Results on water absorption of TRGPC

	No NaOH Concentration Percentage of			Change in mass (Kg)		
5I.NO.	NaOH Concentration	Al ₂ O ₃	Actualiviass (kg)	7days	14 days	30 days
1		-	2.43	2.44	2.47	2.40
2	12M 14M	1%	2.39	2.41	2.43	2.37
3		2%	2.37	2.38	2.39	2.36
4		-	2.40	2.42	2.43	2.40
5		1%	2.39	2.40	2.43	2.35
6		2%	2.45	2.46	2.49	2.40

Table 6. Residual strength of TRGPC after exposure of HCI

SI.No.	NaOH Concentration	Percentage of Al_2O_3	Actual Compressive strength (MPa)	Residual Compressive strength (MPa)
1	_	-	33.42	30.79
2	12M	1%	35.57	31.28
3	-	2%	44.34	36.67
4	_	-	37.83	34.91
5	14M	1%	36.97	29.44
6	_	2%	28.55	26.22



Figure 8. Change in mass - after exposure to HCl

The acid resistance of 12M-1% and 2% specimens revealed lower losses than other specimens after the addition of Al_2O_3 had a positive effect. Weight first rose up to 14 days after exposure. After 30 days of exposure to 5% HCl, the percentage strength losses ranged from 3 to 7% (corresponding weight losses ranged from 0.1% to 4.5%).

It is evident from the current study that the performances of Al₂O₃ added TRGPC samples are comparable to those of the Rice husk ash based GPC even when exposed to a comparably higher concentration of HCl, while they have performed significantly better than the conventional concrete from the aforementioned literature. However, the 14M-2% of Al₂O₃ specimens did not provide much resistance against HCl due to their poor structural compatibility and they showed larger weight and compressive strength losses at the conclusion of the 30 day exposure period.

The visual examination concludes the 12M, 14M, and 2% of Al_2O_3 mixes obtain colour changes in bottom centered.

5.3.2. Sulphate attack

To determine the first corrosion behaviour, weight and compressive strength losses of TRGPC were measured at 1, 7, and 30 days after exposure to a 5% solution of MgSO4. In Table 7 and Figure 11, the weight (actual mass and change in mass) are displayed. Strength variations are depicted in Table 8 and Figure 12.



Figure 9. Residual strengh - after exposure to HCl



Figure 10. After exposure of HCl

Table 7. Change in mass of TRGPC after exposure of MgSO₄

SLNo	NaOHConcontration	Percentage of	ActualMass		Change in mass (Kg)
51.100.	NaOnconcentration	Al ₂ O ₃	(Kg)	7days	14 days	30 days
1		-	2.41	2.43	2.45	2.36
2	12M 	1%	2.38	2.40	2.41	2.37
3		2%	2.42	2.43	2.44	2.40
4		-	2.42	2.43	2.44	2.39
5		1%	2.43	2.45	2.49	2.36
6		2%	2.43	2.46	2.50	2.34



Figure 11. Change in mass - after exposure to MgSO₄



Table 8. Residual strength of TRGPC after exposure of MgSO4

Sl.No.	NaOH Concentration	Percentage of Al ₂ O ₃	Actual Compressive strength (MPa)	Residual Compressive strength (MPa)
1		-	33.42	30.92
2	12M	1%	35.57	32.09
3		2%	44.34	37.43
4		-	37.83	34.01
5		1%	36.97	30.02
6		2%	28.55	27.23

Initially the weight gets increased upto 14 days of exposure toMgSO₄ because of the specimens are oven cured under dry condition. So it absorbed and fill the pores laterally it get affects the specimen losses the weight in 30 days. Al₂O₃ was added, and it improved the

acid resistance of the 12M-2% and 14M-1% specimens, resulting in smaller losses than the other specimen. After 30 days of exposure to 5% MgSO4, the percentage strength losses ranged from 2 to 5% (corresponding weight losses ranged from 0.2% to 3%). It is evident from



the current investigation that the 14M-2% Al_2O_3 specimens did not provide much resistance against MgSO4, and at the conclusion of the 30 day exposure period, they showed increased weight and compressive strength losses due to their poor structural compatibility.

The visual examination concludes the 12M, 14M, and 2% of Al_2O_3 mixes obtain colour changed in side faces.

5.4. Thermal property

5.4.1. Residual Compressive strength

The cube specimens were oven cured at 60°C and cured specimens were exposed to high temperature 200 °C, 400 °C, 600 °C and 800 °C for 1 hour. Following exposure to high temperatures, the results as measured by changes in mass and residual compressive strength of TRGPC were discussed (Figure 13).

Table 9. Residual strength of TRGPC after exposure of 200°C

Figure 13. After exposure of MgSO₄

44.34 45.65

12M-With

2%

Percentage of Al₂O₃

Figure 15. Residual strength–after exposure of 400°C

37.83

14M-

Without

36.60 36.97^{37.10}

34.33

28.55

14M-With 14M-With

2%

1%

41.90

40.16

33.42

12M-

Without

35.57

12M-With

1%

Sl.No.	NaOH Concentration	Percentage of Al ₂ O ₃	Actual mass (kg)	Change in mass (kg)	Residual strength(MPa)
1		-	2.448	2.451	39.12
2	12M	1%	2.339	2.342	48.19
3		2%	2.290	2.293	55.58
4		-	2.349	2.353	42.50
5	14M	1%	2.347	2.350	45.10
6		2%	2.441	2.446	51.05
Table 10. Residual strength of TRGPC after exposure of 400°C					

Sl.No.	NaOH Concentration	Percentage of Al ₂ O ₃	Actual mass (kg)	Change in mass (kg)	Residual strength (MPa)
1		-	2.41	2.32	40.16
2	12M	1%	2.38	2.32	41.90
3		2%	2.39	2.31	45.65
4		-	2.56	2.51	36.60
5	14M	1%	2.42	2.36	37.10
6	_	2%	2.30	2.22	34.33

50

45

5 0



Table 11. Residual	able 11. Residual strength of TRGPC after exposure of 600°C								
Sl.No.	NaOH Concentration	Percentage of Al ₂ O ₃	Actual mass (kg)	Change in mass (kg)	Residual strength (MPa)				
1	12M	-	2.45	2.38	32.01				
2		1%	2.40	2.33	31.30				
3		2%	2.34	2.27	43.22				
4	14M	-	2.52	2.44	30.01				
5		1%	2.37	2.30	31.92				
6		2%	2.41	2.33	36.14				





Figure 16. Residual strength – after exposure of 600°C

Table 12. Residual strength of TRGPC after exposure of 800°C



Figure 17. Residual strength – after exposure of 800°C

Sl.No.	NaOH Concentration	Percentage of Al ₂ O ₃	Actual mass (kg)	Change in mass (kg)	Residual strength (MPa)
1	12M	-	2.39	2.27	20.19
2		1%	2.39	2.30	24.30
3		2%	2.45	2.36	26.89
4	14M	-	2.48	2.40	21.90
5		1%	2.45	2.36	23.04
6		2%	2.46	2.38	21.01

The residual strength and change in mass were drawn, according to Table 9. The weight of the specimen decreases from 1 to 3% of the actual mass. But the residual strength is higher than the actual compressive strength. Then the 12M - addition of Al_2O_3 gives the higher residual strength shown in Figure 14. Because of the GPC get more active upto 200 °C and yields the high strength referred in previous research work. The visual observation of after exposure at 200 °C remains no cracks.

Table 10 indicates that the residual strength and change in mass were taken into consideration. The weight of the specimen decreases from 2 to 7% of the actual mass. Then the residual strength is higher than the actual compressive strength. But the rate of increasing is decreased compared to 200 °C exposures. When the combination of 12M-2% of Al_2O_3 is gives the optimum value shown in Figure 15. The visual observation of after exposure at 400 °C remains no cracks are obtained.

The residual strength and change in mass were extracted from Table 11. The weight of the specimen decreases from 5 to 10% of the actual mass. The residual strength is decreased because of dehydroxylation and it obtains minimal shrinkage. This 12M-2% Al_2O_3 yields satisfactory results. And compared to actual compressive strength, residual strength from 14M-2% Al_2O_3 is higher. 12M and 14M were visually observed to have surface edge hair line cracks following exposure to 600 °C.

The residual strength and change in mass were taken from Table 12. The weight decreases 8 to 15% from the actual mass. The residual strength is decreased and rate of decreasing is high compared to 600 °C exposure specimen. The 12M and 14M specimens are densed by

vitreous sintering compared to % Al_2O_3 of specimens. The visual observation of after exposure at 800 °C, 12M and 14M having hair line cracks occurred in surface and 2% of Al_2O_3 occurs crack in corners shown in Figure 18.



Figure 18. After exposure of heat

6. Conclusions

- The experimental results demonstrated that utilising rice husk ash and aluminium oxide, it is feasible to produce geopolymer concrete with significant strength and durability.
- The compressive strength increased as NaOH concentration raised.
- For the corresponding in 12 molarity and percentage of adding aluminium oxide, the strength increase varied from 5 to 10%.
- When aluminium oxide was added to Rice husk ash-based TRGPC, the mechanical qualities showed promise when compared to mixes with 14 molar concentration.

- Lower water absorption is the result of silicate and aluminium oxide filling the gaps between the rice husk ash particles. As the proportion of Al₂O₃ increased at 12M, the water absorption dropped linearly.
- According to the durability experiments, specimens with a 12M-2% Al₂O₃ content demonstrated good resistance to acid and sulphate assault since their weight and strength losses were lower than those of the other specimens.
- Compared to the actual compressive strength of oven curing, rice husk ash-based geopolymer concrete experiences a high strength during its early heating period (up to 200oC). Compared to other specimens, the residual strength in the 12M-2% Al2O3 exhibited high results.
- The unreacted crystalline components of geopolymer concrete are converted to an amorphous state and go through polymerization at an exposure temperature of 600 °C. As a result, the strength loss in geopolymer is marginally reduced. Up to 600 °C, the geopolymer concrete showed no discernible cracks, and at an exposure temperature of 800 °C, only small fissures appeared.
- The experimental research leads to the conclusion that, out of six mixtures, 12M-1% and 12M-2% of Al2O3 are the best.

Environmental application

- In view of the environmental degradation caused by the cement industry, an attempt has been made in this work to develop geopolymer concrete using Rice husk ash which is industrial by product as replacement for cement, and to assess their strength and durability properties.
- In spite of enhancing the thermal resistant property by adding an aluminum oxide was used. Since aluminum oxide has high melting point. It induces a better performance geopolymer concrete base pad.
- The amorphous inorganic structure of the geopolymers lends itself to good thermal resistance which leads to potential applications as thermal insulation in industrial, military, molten mineral processing, Food processing units, Oven bases, chimney and domestic sectors.

Scope for further research

The paper has dealt with the experimental investigation on thermal resistant geopolymer concrete with aluminium oxide. The following suggestions are given for further research in thermal resistant geopolymer concrete:

• Further work shall be done by varying the NaOH concentration from 6M to 16M and also varying the temperature for conducting thermal test.

- Various agricultural and industrialwastes by products can be used instead of Rice husk ash.
- Increase the percentage of Al2O3 for increase the thermal resistance and different chemicals having high melting point shall be used.
- Study will be extended to evaluate the permeability, durability and thermal properties like laser flash diffusivity, transient hot wire test etc., after exposure of heat.

References

- Abdullah A., Abdullah M.M.A.B., Hussin K. and Tahir M.F.M. (2017). Effect of different sintering temperature on fly ash
 Based geopolymer artificial aggregate, *AIP Conference Proceedings*, **1835**, 020050
- Albitar M., Ali M.M., Visintin P. and Drechsler M. (2017). Durability evaluation of geopolymer and conventional concretes, *Construction and Building Materials*, **136** 374–385
- Ayswarya E.P., Nair A.B. and Thachil E.T. (2021). A comparative study of mechanical, dynamic mechanical and thermal properties of rice husk ash, modified rice husk ash and nano silica filled epoxy composites, *Materials Today: Proceedings*, 1–7 (2021).
- Babaee M and Castel A. (2016). Chloride-induced corrosion of reinforcement in low-calcium fly ash-based geopolymer concrete, *Cement and Concrete Research*, **88**, 96–107
- Elyamany H.E., AbdElmoaty M. and Elshaboury A.M. (2018). Magnesium sulfate resistance of geopolymer mortar, *Construction and Building Materials*, **184** 111–127
- Elyamany H.E., AbdElmoaty M. and Elshaboury A.M. (2018). Setting time and 7-day strength of geopolymer mortar with various binders, *Construction and Building Materials*, **187**, 974–983
- Hardjito D., Wallah S.E., Sumajouw D.M. and Rangan B.V. (2004). On the development of fly ash-based geopolymer concrete, 01-M52 ACI Materials Journal
- Jaishankar P and Karthikeyan C. (2017). Characteristics of Cement Concrete with Nano Alumina Particles, IOP Conf. Series: Earth and Evironmental Science, **80**, 012005
- Law D.W., Adam A.A., Molyneaux T.K., Patnaikuni I. and Wardhono A. (2015). Long term durability properties of class F fly ash geopolymer concrete, *Materials and Structures* 48:721–731
- Luhar S., Chaudhary S. and Luhar I. (2018). Thermal resistance of fly ash based rubberized geopolymer concrete, *Journal of Building Engineering*, S2352-7102, 30084-6
- MallikarjunaRao G. and GunneswaraRao T.D. (2015). Final Setting Time and Compressive Strength of Fly Ash and GGBS-Based Geopolymer Paste and Mortar, Springer Arabian journal for science and engineering **40**:3067–3074
- Montes C., Allgood D., Allouche E. and Islam R. and Tham I. (2014). Evaluation of geopolymer concrete for repair of rocket test facility flame deflectors, *taylor&francis group*, ISBN 978-1-138-02708-4
- Murugesan S.R., Sivakumar V. and Panneerselvam M. (2022). Biosorption of Malachite Green from Aqueous Phase by Tamarind Fruit Shells Using FBR, *Advances in Materials Science and Engineering*. https://doi.org/10.1155/ 2022/8565524

- Nazari A. and ShadiRiahi. (2012). The effect of aluminium oxide nanoparticles on the compressive strength and structure of self-compacting concrete, *Magazine of Concrete Research*, 64(1), 71–82
- Ramesh K. (2014). An experimental study on effect of aluminum oxide on strength and corrosion resistance of concrete, *International Journal of Engineering Research & Technology*, ISSN: 2278-0181, 3 (11), November-2014
- Rickard W.D., Riessen A.V. and walls P. (2010). Thermal Character of Geopolymers Synthesized from Class F Fly Ash Containing High Concentrations of Iron and a-Quartz, International Journal of Applied Ceramic Technology, 7(1) 81–88
- Sakkas K., Kapelari S., Panias D., Nomikos P. and Sofianos A. (2014). Fire Resistant K-Based MetakaolinGeopolymer for Passive Fire Protection of Concrete Tunnel Linings, Open Access Library Journal, 1: e806
- Sashikkumar M.C., Raja K., Senthil Kumaran Selvaraj A. and Rajan J. (2022). Performance of Polyvinyl Alcohol and Polypropylene Fibers under Simulated Cementitious *Composites Pore Solution*, 9669803 https://doi.org/10.1155/ 2022
- Sathanandam T., Awoyera P.O., Vijayan V. and Sathishkumar K. (2017). Low carbon building: Experimental insight on the use of fly ash and glass fibre for making geopolymer concrete, *Sustainable Environment Research*, **27** 146e153
- Saxenaa S.K., Kumar M. and Singha N.B. (2017). Fire Resistant Properties of Alumino Silicate Geopolymer cement Mortars, *Elsevier-Materials Today: Proceedings* **4** 5605–5612
- Shaikh F.U. (2014). Effects of alkali solutions on corrosion durability of geopolymer concrete, Advances in Concrete Construction, 2(2), 109-123
- Somna R., Saowapun T., Somna T. and Chindaprasirt P. (2022). Rice husk ash and fly ash geopolymer hollow block based on NaOH activated, *Case Studies in Construction Materials*, 1– 12, **16**, e01092
- Umniati B.S., Risdanareni P. and Zein F.T.Z. (2017). Workability Enhancement of Geopolymer Concrete through the use of retarder, AIP Conference Proceedings, 1887, 020033
- Vignesh S.R., Vivek V., Priya K. and Thanukrishna. (2020). Experimental Investigation on Bricks by Using Cow Dung, Rice Husk, Egg Shell Powder as a Partial Replacement for Fly Ash **9** https://doi.org/10.51983/tarce-2020.9.2.2556
- Voraa P.R. and Dave U.V. (2013). Parametric Studies on Compressive Strength of Geopolymer Concrete, *Elsevier Procedia Engineering*, **51**,210–219
- Wijaya A.L. and Ekaputri J.J. (2017). Factors influencing strength and setting time of fly ash based-geopolymer paste, *MATEC Web of Conferences* **138**, 01010.
- Wun B., Xiong W. and Wen B. (2014). Thermal fields of cracked concrete members in fire, *Fire Safety Journal*, **66**, 15–24
- Zainal F F., Amli S F M., Hussin K., Rahmat A. and Abdullah M.M.A.B. (2017). Corrosion Studies of Fly Ash and Fly Ash-Slag Based Geopolymer, *Materials Science and Engineering*, 209 012026