EXPERIMENTAL INVESTIGATION OF GEOPOLYMER BRICK FOR STRENGTH AND DURABILITY

[1]Priyanka Salunkhe, [2]Abhijeet Keskar, [3]Prathamesh Balip, [4]Tejas Deshmukh, [5]Siddesh Gadge, [6]Prasad Vhanmane

[1]Associate Professor, Department of Civil Engineering, [2]Assistant Professor, Department of Civil Engineering, [3,4,5,6] BE Final Year Student, Department of Civil Engineering

[1]Department Civil Engineering
[1]Terna Engineering College, Nerul, Navi Mumbai, India-400706.

Abstract : The mixture of aluminosilicate material such as fly ash, silica fume with an alkaline solution such as sodium hydroxide & sodium silicate completes the geopolymerization process and forms an activated alkaline solution that has the binding property. This activated alkaline solution is mixed with white clay and produces the geopolymer brick. The various trial mixes are worked out with an AAS/FA ratio between 0.4 to 0.5, Na_2SiO_3/NaOH ratio between 2 to 3, and molarity of alkaline solution between 12M to 16M. The various trial mix bricks will be prepared and oven cured at 70°c ambient temperature. The brick is then analyzed for compressive strength and Durability tests. The maximum compressive strength is achieved up to 5.1 N/mm^2 & water absorption of 5% when it is heated at 70°c for 7 days. Microstructure Analysis tests such as X-Ray Diffraction Test (XRD) is carried out on material. The geopolymerization reaction resulting in a formation of new product with different microstructure.

IndexTerms - Alkaline solution, Microstructure of the material, Geopolymerization, etc.

1. INTRODUCTION

Bricks are a construction material widely used in the construction industry. It serves as a partition member or wall component in the building. Brick is made from cement and mud clay with other fine aggregate material to achieve maximum structural and mechanical properties. Cement and mud are the binders used for binding the materials to form a brick. The manufacturing of cement requires more energy to form cement powder from rock and while processing 80 % of CO_2 gas is evolved in the atmosphere which causes an increase in greenhouse gas emission. The brick is burned by using coal, wood, and fuel at 900°c to 1100°c to achieve structural and mechanical property. While burning the brick carbon dioxide (CO_2) emission takes place, which affects the ozone layer and helps further to increase global warming. The forming of brick from cement and clay mud requires more natural materials which reduce the natural resources and it was harmful to the environment.

To counteract this negative environmental impact, geopolymer material was discovered to be the best substitute for cement as a binder material in the nineteenth century [20, 21]. The geopolymer brick is a type of brick made from industrial waste that has a high aluminosilicate content and is geopolymerized with an alkaline solution [12]. The geopolymerization is the technique that transforms various solid aluminosilicate materials into a useful product.

In this study, the mixture of aluminosilicate material such as fly ash, silica fume with an alkaline solution such as sodium hydroxide and sodium silicate completes the geopolymerization process and forms an activated alkaline solution that has the binding property. This activated alkaline solution is mixed with white clay and produces the geopolymer brick. The various trial mixes are worked out with an AAS/FA ratio between 0.4 to 0.5, Na_2SiO_3/NaOH ratio between 2 to 3, and molarity of alkaline solution between 12M to 16M. The various trial mix bricks will be prepared and oven cured at 70°c ambient temperature. The brick is then tested for Compressive strength, Durability test, and Microstructural tests. The result of each test is analyzed and the final conclusion of material regarding overall property is workout.

2. RESERCH METHODOLOGY

2.1. MATERIALS

2.1.1. AluminoSilicate Material

Industrial waste are mainly aluminosilicate materials which are rich in silica and alumina content and that's why they known as aluminosilicate material [5,6]. They are helpful in generation of critical geopolymer structure which is stable by mainatining Si/Al molar ratio.The stable structure increses all physical, chemical and mechanical properties of geopolymer material and enhance the performance of geopolymer material under various conditions [3, 19, 21].

2.1.1.1. Fly Ash: (Class F)

The various types of fly ash are available in the market, mainly C-type and F-type fly ash. The classification of fly ash is based on fineness and CO_2 content present in it. The Table 1 shows that the low calcium-based fly ash (Class F) is used in the project to produce less greenhouse gas emission material known as geopolymer material in form of a brick. Fly ash is pozzolanic aluminosilicate material having high alumina and silica content. This content is used to produce a geopolymerization process. The geopolymer brick made up of a mixture of low calcium-based fly ash (class f) with an Activated alkaline solution, has excellent compressive strength [17,18].

Table 1 Properties & Chemical Composition of Fly Ash

TEST NAME		Unit	Result	Specification As per IS:3812(Part-1)-2003
CHEMICAL PARAMETER				
1	Silicon dioxide, as SiO_2	%	61.40	Min. : 35
2	$SiO_2 + Al_2O_3 + Fe_2O_3$	%	90.60	Min. : 70
3	Reactive Silica	%	34.50	Min. : 20
4	Magnesium Oxide (MgO)	%	1.45	Max.: 5.0
5	Total Chlorides	%	0.03	Max.: 0.05
PHYSICAL PARAMETERS				
6	Specific Gravity	-	2.3	-
7	Density	Kg/m^3	1286	-
8	Loss on Ignition	%	0.9	Max.: 5.0
9	Fineness Specific Surface by blain	M^2/Kg	341.70	Min. : 320
10	Moisture	%	0.80	Max.: 2.0
11	Passing on 45 Micron Sieve (Wet Sieving)	%	59.30	Min. : 66
12	Retention on 45 Micron Sieve (Wet Sieving)	%	40.70	Max.: 34

2.1.1.2. Silica Fume:

Silica fume is a fine material with spherical particles less than 25 microns in diameter. This is much smaller than the average cement particle. The silica fume is very fine and has a more specific surface area and improves the density when water is added to it. The silica fume having high silica content up to 98% and calcium content is less than 1%, which is beneficial to cast geopolymer material with a low calcium content. Silica fume is helpful to maintain Si/Al ratio between 1 to 3 which is helpful to improve brick properties, in particular its compressive strength, bond strength, and abrasion resistance. The addition of silica fume also reduces the permeability of brick by reducing voids present in brick. It improves the performance of geopolymer material. As the amount of silica fume increases the workability of geopolymer decreases due to the high surface area of silica fume particles. Segregation and bleeding are reduced by silica fume due to the absorption of extra water. The silica fume is having lots of advantages but as the amount of silica, fume increases directly affects the cost of material so the use of 1% to 2% silica fume shows effective compressive strength increase with all other properties.

2.1.2. Alkaline Solution

The Alkaline solutions are prepared from base material mixed with water and by heating at a temperature between 900°c to 1100°c. These alkaline solutions are rich in silica and alumina content having pH greater than 7. The alkaline solution with a proper amount of sodium silicate to sodium hydroxide molarity ratio produces the binding property and stabilizes the geopolymer chemical structure which helps in increase all properties of the material [4, 12, 15, 20]. The Activated Alkaline Solution such as Sodium Silicate and Sodium Hydroxide is used in this project so the Geopolymerization process forms and produces binding property.

2.1.2.1. Sodium Hydroxide (NaOH):

It was the inorganic base chemical material having purity of 98% shown in Table 2 and it is used to prepare activated alkaline solution while mixed with aluminosilicate material by maintaining proper molarity. Maintain proper molarity to form concentrated solution play a very important role in binding property. The molarity maintained from 12M to 16M useful to form a stable chemical structure with strength properties.

1 Molar solution = 48 gm NaOH in 1 liter water

Table 2 Properties of Sodium Hydroxide

MAXIMUM LIMIT OF PUARITY	
Sodium Hydroxide	98%
PHYSICAL PARAMETERS	
Specific Gravity	1.53
Density **(**Kg/m^3)	2130

2.1.2.2. Sodium Silicate (Na_2SiO_3):

It was a colorless transparent solid which is adhesive in nature. This chemical material is used to prepare activated alkaline solution while mixed with aluminosilicate material by maintaining proper molarity. Maintaining proper molarity to form concentrated solution play a very important role in binding property. The molarity maintained from 12M to 16M useful to form a stable chemical structure with strength properties.

Table 3 Properties of Sodium Silicate Liquid Solution

Sr. No.	Test	Results
1	Na_2O content	16.70°c
2	SiO_2 content	36.60°c
3	Ratio of $Na_20:SiO_2$	1:2.2 (by wt ratio)
4	Insoluble matter	Nil
5	Specific gravity at 27.0°c	1.56
6	Density **(**Kg/m^3)	1490

2.1.3. White Clay

The Figure 1 is the XRD Test Graph which shows the white clay is having maximum Silica content and used up to 70% to 85% while preparing geopolymer brick as per mix design. The silica content present in white clay will help to maintain the Si/Al ratio

in between 1 to 3 and which is required to prepare a critical geopolymer chemical structure. This structure helps in the improvement of strength, mechanical and fire-resisting properties. The fineness of clay is between 150 microns to 4.5 mm and also all other test results are shown in Table 4. As the white clay is used between 75% to 85% the cost of geopolymer material is reduced and the brick will be economical.

Table 4 Test Result of White Clay

Test	Result
Specific Gravity	2.08
Density	2040.48 Kg/m^3
Water Content	0.87 %

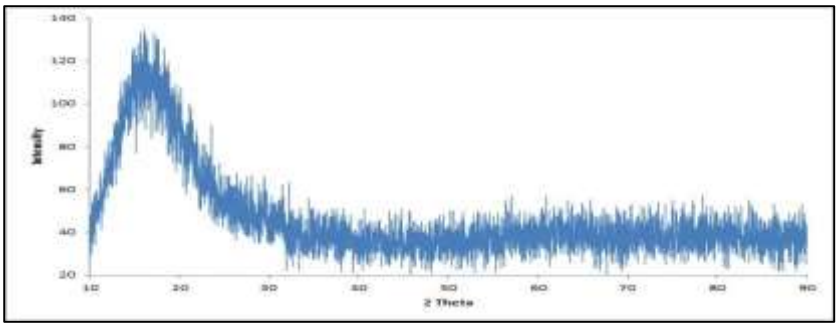

Fig. 1 XRD Test Graph of White Clay

2.2. MIX DESIGN

The various factors are governed to form geopolymerization which was taken into account while preparing mix proportioning. The only use of one alkaline solution was not to give effective results so use at least 2 different alkaline solutions with maintaining the proper ratio to get effective results. C. Freidin 2007 tells As sodium silicate and sodium hydroxide content increase the compressive strength of geopolymer increases. The mixture of aluminosilicate (silicon dioxide (SiO_2) and aluminum dioxide (Al_2O_3)) with sodium silicate (Na_2SiO_3) is required to make water-resistant geopolymer material. Maintaining morality of alkaline solution from 5M to 15M. Water to geopolymer binder ratio <0.35, Solution to aluminosilicate ratio <0.35, Sodium Silicate to Sodium hydroxide ratio equal to 1 makes geopolymer material hydrostatically stable and critical which gives all physical and mechanical properties. The compressive strength of Geopolymer concrete decreases as the water to Geopolymer solid ratio by mass increases.

The various trial mixes are worked out with an AAS/FA ratio between 0.4 to 0.5, Na2SiO3/NaOH ratio between 2 to 3, molarity of alkaline solution between 12M to 16M, Water to geopolymer binder ratio <0.35, and Solution to aluminosilicate ratio <0.35.

For Mix Design Refer IS 10262:2019

Only cement is replaced by alkaline activation solutions and their quantity is calculated as per following method:

Determination of Activator Content: (Quantity of NaOH & Na_2SiO_3)

$$\frac{MNa2SiO3}{MNaOH} = R \qquad (1)$$

Where, M = Mass in Kg

R = Ratio (Assume Na2SiO3/NaOH ratio between 2 to 3)

MAAS = Mass of Alkaline Activator Solution = Water Content in IS 10262:2019

MNaOH = Mass of NaOH

Na_2SiO_3 = Mass of Na_2SiO_3

MAAS = MNaOH + MNa_2SiO_3 (2)

= MNaOH + (R x MNaOH) From (1)

MAAS = MNaOH(R + 1) (3)

$$MNaOH = \frac{MAAS}{R+1}$$ From (3)

MNaOH = …….. Kg/m^3

MNa_2SiO_3= R x MNaOH From (1)

MNa_2SiO_3= …….. Kg/m^3

Table 5 Trials of mix design

Trial Mix (T)	Ratios				Final Quantity (Kg/m^3)								
	AAS / FA	Na_2SiO_3 / NaOH	Molarity	W / G	Fly Ash	Silica Fume	NaOH	Na_2SiO_3	Water in NaOH	Water in Na_2SiO_3	Clay	Water remaining	Total weight
T1	0.5	2	12	0.199	414	46	24.96	90.72	52	63	1834.13	115	2639.81
T2	0.5	2	12	0.159	374.4	41.6	22.56	138.28	47	0	1748.75	122	2494.59
T3	0.4	2	16	0.112	468	52	26.88	138.41	42	0	1288.99	134.5	2150.79
T4	0.4	3	12	0.122	468	52	17.04	156	35.5	0	1289.44	128.5	2146.49
T5	0.4	3	16	0.102	468	52	20.48	155..99	32	0	1289.44	140.5	2158.42
T6	0.5	2	12	0.159	374.4	41.6	22.56	138.28	47	0	1383.04	122	2128.88
T7	0.5	2	16	0.134	374.4	41.6	27.2	138.41	42.5	0	1383.04	134	2141.16
T8	0.5	3	12	0.145	374.4	41.6	17.04	156	35.55	0	1383.49	128.5	2136.54

3. BRICK PREPARATION

Weight Aluminisilicate materials (Fly ash & Silica Fume), Alkaline Solutions (Solid Sodium Hydroxide & Liquid Sodium Silicate), Dry White Clay and Water required for mix. Prepare mix of Alkaline solution and add dry mixed flyash & silica fume in it. Mixture formed is known as Activated Alkaline Solution which have the binding property. The white clay is then mixed in alkaline activated binder and homogeneously mixed. The formation of geopolymer is takes place after mixed it. The mixture is then placed in brick mould of size 235mm x 110mm x 85mm. The brick is then removed in half hr and placed in oven for ambient temperature curing at 70 for 7 days. Then the geopolymerization takes place while curing and the brick is tested for Strength, Durability and Microstructure Analysis.

4. RESULT & DISCUSSION

The result discusses about Compressive strength, Durability test, and Microstructure Analysis tests.

4.1. Compressive Strength

The Compressive Strength of geopolymer brick is carried out by UTM, as per procedure given in IS 3495 (Part 1) : 1992 specified for Methods of test of burnt clay building brick. Part 1 for Determination of Compressive Strength.

Table 6 Compressive Strength

Trial No.	Dimensions (mm)	Avg. Weight (Kg)	Avg. Compressive Strength (N/mm^2)
T1	235 x 110 x 85	3.40	2.1
T2	235 x 110 x 85	3.46	5.1
T3	235 x 110 x 85	3. 39	2.88
T4	235 x 110 x 85	3.40	2.57
T5	235 x 110 x 85	3.54	3.9
T6	235 x 110 x 85	3.28	2.63
T7	235 x 110 x 85	3.38	3.29
T8	235 x 110 x 85	3.49	3 .38

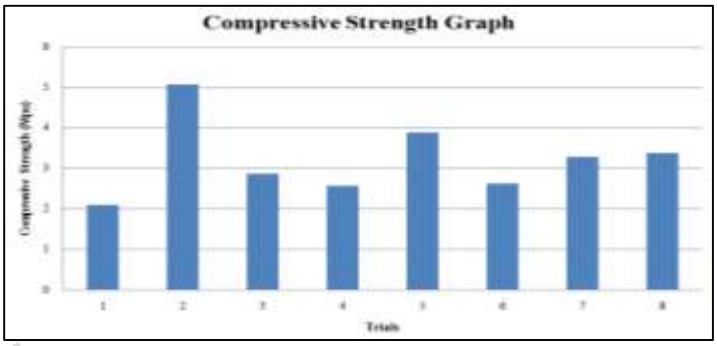

Fig. 2 Compressive Strength Graph of Geopolymer Brick Mix Trials

It has been seen that the Trail no. 2 in Table 6 shows that it have more strength up to 5.1 N/mm^2 as compared to all other trials when it is heated at 70°c for 7 days. The various ratios such as AAS / FA = 0.5, Na_2SiO_3/ NaOH = 2, Molarity = 12, W/G = 0.159 are maintained properly as mentioned in Mix design part. The trial is may forms proper alkaline activator solution or geopolymerization reaction which have binding property and have good bond strength as discussed in FTIR Test. The given ratios are best suited for the brick which is made from F Type Fly Ash, Silica Fume & White clay to achieve strength.

4.2. Water Absorption

The Water Absorption of gropolymer brick is carried out as per procedure given in IS 3495 (Part 2) : 1992 specified for Methods of test of burnt clay building brick. Part 2 for Determination of Water Absorption.

W1 = weight of oven dried brick (kg)
W2 = saturated weight of brick (kg)
Water Absorption = (W2-W1)/W1 ×100

Table 7 Water Absorption

Trial	W1 (kg)	W2 (kg)	Avg. Water Absorption (%)	Remark
T1	3.40	3.51	3.29	< 15%, So ok.
T2	3.46	3.64	5.00	< 15%, So ok.
T3	3.39	3.67	8.25	< 15%, So ok.
T4	3.40	3.51	3.19	< 15%, So ok.
T5	3.54	3.69	4.29	< 15%, So ok.
T6	3.28	3.36	2.40	< 15%, So ok.
T7	3.38	3.64	7.89	< 15%, So ok.
T8	3.49	4.17	19.37	> 15%, So Not ok.

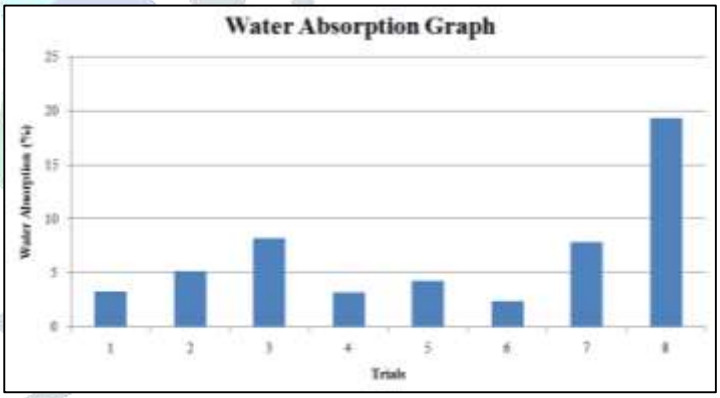

Fig. 3 Water Absorption Graph of Geopolymer Brick Mix Trials

It has been seen that the Trail no. 2 in Table 6 shows that it have more strength up to 5.1 N/mm^2 as compared to all other trials when it is heated at 70°c for 7 days but have water absorption as 5% as per Table 7. This water absorption is more than Trial no. 1, 4, 5 & 6 but ok as it should less than 15%. So, we can adopt this trial as best trial for strength as well as for durability.

5. CONCLUSION

1. The Figure 1 of XRD graph shows that the White Clay used in preparation of geopolymer brick is have more than 65% of Silica content and it is helpful in geopolymerization process.
2. Through maintain various ratios such as AAS / FA = 0.5, Na_2SiO_3/ NaOH = 2, Molarity = 12, W/G = 0.159 as discussed in Mix Design part we achieve maximum strength up to 5.1 N/mm^2 as compared to all other trials when it is heated at 70°c for 7 days. This brick is classified as 2nd class brick.
3. The brick with Trial no. 2 have maximum strength as well water absorption up to 5% and which is less than 15% as per IS 3495 (Part 2) : 1992. So, the brick is classified as 1st class brick.

So, the geoplymer brick have the strength and durability property when proper quantity of each material is used and it is free from greenhouse gases emission in environment.

REFERENCES

[1]. K. Shrinivasan and A. Sivakumar, (2013), "Geopolymer binders: A need for future concrete construction", ISRN polymer science, Vol. 2013, Article ID 509185, Hindawi publications. (https://dx.doi.org/10.1155/2013/509185)

[2]. D. Dimas, I. Giannopoulou and D. Panias, (2019), "Polymerization in sodium silicate solution: a fundamental process in geopolymerization technology", J Mater Science, vol. 44, pp 3719-3730. (DOI 10.1017/s10853-009-3497-5)
[3]. P. Duxson, A. Fernandez-Jimenez, J. KL. Provis, G. C. Lukey, A. Palomo and J. S. J. Van Deventer, (2007), "Geopolymer technology: the current state of the art", J Mater Science, vol. 42, pp 2917-2933. (DOI 10.1007/s10853-006-0637-z.)
[4]. Anuj Kumar and Sanjay Kumar, (2012), "Development of paving blocks from synergistic use of red mud and fly ash using geopolymerization", Construction and Building materials, vol. 38, pp 865-871. (https://dx.doi.org/10.1016/j.conbuildmat.2012.09.013)
[5]. AprianySaludung, Yuko Ogawa and Kenji Kawai, (2018), "Microstructural and mechanical properties of FA/GGBS-based geopolymer", MATEC Web of Conference, vol. 195. (https://doi.org/10.1051/matecconf/201819501013)
[6]. Palomo, M. W. Grutzeck and M. T. Blanco, (1999), "Alkali-activated fly ashes: A cement for the future, Cement and Concrete Research, Vol. 29 (8), , PP. 1323-1329. ((https://doi.org/10.1016/S0008-8846(98)00243-9).
[7]. S. Mohammeda, M. S. Liewa, W. S. Alaloula, A. Al-Fakiha,W. Ibrahima and M. Adamu, (2018), "Development of rubberized geopolymer interlocking bricks", Case Studies in Construction Materials, Vol. 8, PP. 401-408.
[8]. S. Ahmari and L. Zhang, (2012),"Production of eco-friendly bricks from copper mine tailings through geopolymerization", Construction and Building Materials Vol. 29, PP. 323–331. (doi:10.1016/j.conbuildmat.2011.10.048).
[9]. L. Murmu and A. Patel, (2018),"Towards sustainable bricks production: An overview", Construction and Building Materials, Vol. PP. 165 112–125. (https://doi.org/10.1016/j.conbuildmat.2018.01.038).
[10]. P. Turgut and M. Algin, (2007),"Limestone dust and wood sawdust as brick material", Building and Environment, Vol. 42, PP. 3399–3403.
[11]. Aalil , D. Badreddine , K. Beck , X. Brunetaud , K. Cherkaoui , A. Chaaba and M. Al-Mukhtar, (2019), "Valorization of crushed bricks in lime-based mortars", Construction and Building Materials, Vol. 226, PP. 555–563.
[12]. G. Cultrone, I. Aurrekoetxea, C. Casadoand A. Arizzi, (2020), "Sawdust recycling in the production of lightweight bricks: How the amount of additive and the firing temperature influence the physical properties of the bricks", Construction and Building Materials, Vol. 235, PP. 117436.
[13]. P. Palanisamya and P. Suresh Kumar, (2018), "Effect of molarity in geo polymer earth brick reinforced with fibrous coir wastes using sandy soil and quarry dust as fine aggregate.", Case Studies in Construction Materials, Vol. 8, PP. 347–358.
[14]. H. Madani , A. Ramezanianpour , M. Shahbazinia and E. Ahmadi, (2020), "Geopolymer bricks made from less active waste materials", Construction and Building Materials, Vol. 247, PP. 118441. (https://doi.org/10.1016/j.conbuildmat.2020.118441)
[15]. Fadele O.A and Ata O (2018),"Water absorption properties of sawdust lignin stabilised compressed laterite bricks",
[16]. C. Freidin (2007), "Cementless pressed blocks from waste products of coal-firing power station", Construction and Building Materials, (https://doi.org/10.1016/j.conbuildmat.2020.118441)
[17]. Lianyang Zhang , Saeed Ahmari and Jinhong Zhang, (2011),"Synthesis and characterization of fly ash modified mine tailings-based geopolymers", Construction and Building Materials, Volume 25, Issue 9, pp 3773-3781, (https://doi.org/10.1016/j.conbuildmat.2011.04.005)
[18]. Claudio Ferone, Francesco Colangelo, RaffaeleCioffi, Fabio Montagnards and Luciano Santoro, (2011), "Mechanical performance of weathered coal fly ash based geopolymer bricks", International conference on green building and sustainable cities, Procedia Engineering, vol. 21, PP 745-752.
[19]. Ines Garcia-Loderio, Ana Fernandez-Jimenez and Angle Palomo, (2015), "An overview of the chemistry of alkali-activated cement based binders", Materials DE Construction, vol. 64, Issue 315. (DOI: 10.1533/9781782422884.1.19)
[20]. Alkaline cement and Concrete Conference, KIEV University, Ukraine, 1994, pp.131-149
[21]. Geopolymer chemistry and applications
[22]. Laila MardiahDeraman, Liew Yun Ming, Mohd Mustafa Al Bakri Abdullah, H. Kamarudin,(2017) "The Effect of Different Ratio Bottom Ash and Fly Ash Geopolymer Brick on Mechanical Properties for Non-loading Application", MATEC Web of Conferences 97, 01017 (2017) ETIC 2016
[23]. T.Subramani , P.Sakthivel,(2016) " Experimental Investigation On Flyash Based Geopolymer Bricks", Volume 5, Issue 5, May 2016 ISSN 2319 – 4847
[24]. Omer Arioz, KadirKilinc, Mustafa Tuncan , AhmetTuncan and Taner Kavas, (2010), "Physical, Mechanical and Micro-structural Properties of F Type Fly-Ash Based Geopolymeric Bricks Produced by Pressure Forming Process", Advances in Science and Technology, Vol. 69, pp 69-74, TransTech Publications, Switzerland (doi:10.4028/www.scientific.net/AST.69.69)
[25]. Lianyang Zhang, Saeed Ahmari and Jinhong Zhang, (2011), " Synthesis and characterization of fly ash modified mine tailings-based geopolymers", (doi:10.1016/j.conbuildmat.2011.04.005).
[26]. Saeed Ahmari and Lianyang Zhang, (2012), " Production of eco-friendly bricks from copper mine tailings through geopolymerization", (doi:10.1016/j.conbuildmat.2011.10.048).
[27]. Jian He, Jianhong Zhang, Yuzhen Yu and Guoping Zhang, (2012), " The strength and microstructure of two geopolymers derived from metakaolin and red mud-fly ash admixture: A comparative study", (doi:10.1016/j.conbuildmat.2011.12.011).
[28]. Pacheco-Torgal , Z. Abdollahnejad , A.F. Camões , M. Jamshidi and Y. Ding, (2012), " Durability of alkali-activated binders: A clear advantage over Portland cement or an unproven issue?", (doi:10.1016/j.conbuildmat.2011.12.017).
[29]. Jian He, YuxinJie ,Jianhong Zhang , Yuzhen Yu and Guoping Zhang, (2013), "Synthesis and characterization of red mud and rice husk ash-based geopolymer composites", (http://dx.doi.org/10.1016/j.cemconcomp.2012.11.010).
[30]. Vihangraj V. Kulkarni ,Animes Kumar Golder , Pranab Kumar Ghosh (2019),"Production of composite clay bricks: A value-added solution to hazardous sludge through effective heavy metal fixation", Elsevier publications. (https://doi.org/10.1016/j.conbuildmat.2018.12.187)
[31]. FazliSaeeda, Amir Naveedb and Saeed Gul, (2020), "Synthesis of Geopolymeric Membrane Using Locally Available Rice Husk Ash as a Source Material".
[32]. Fernando (2017)," Experimental Investigation of the Effect of Fired Clay Brick on Partial Replacement of Rice Husk Ash (RHA) with Brick Clay Adv Recycling Waste".

[33]. TayfunCicek and Mehmet Tanrıverdi, (2006), " Lime based steam autoclaved fly ash bricks", (doi:10.1016/j.conbuildmat.2006.01.005).
[34]. AprianySaludung, Yuko Ogawa, and Kenji Kawai, (2018)," Microstructure and mechanical properties of FA/GGBS-based geopolymer", published by EDP Sciences. (http://creativecommons.org/licenses/by/4.0/).
[35]. B V Rangan (2006), "Engineering properties of geopolymer concrete".
[36]. Nguyen Hoc Thang, Nguyen Ngoc Hoa, Duong Tan Vu, Pham TrungKien, Michael A. B. Promentilla Faculty of Chemical Engineering, Ho Chi Minh City University of Food Industry,LeTrong Tan Str, Tan Phu Dist., Ho Chi Minh City, Viet Nam (2016),"Properties of Geopolymer from Coal Bottom Ash and Water Glass Solution", (https://www.researchgate.net/publication/309506286).
[37]. J S Sudarsan,S Ramesh, M Jothilingam, VishalatchiRamasamy and Rajitha J Rajan, (2017)," Papercrete brick as an alternate building material to control Environmental Pollution", IOP Conf. Series: Earth and Environmental Science, vol. 80.
[38]. Carlos Mauricio F. Vierira, Regina M. Pinherio, Ruben J. Sanchez Rodriguez, Veronica S. Candido and Sergio N. Monterio,(2016),"Clay bricks added with effluent sludge from paper industry: Technical, Economical and environmental benifites", Appl. Clay Science, Elsevier B.V. Publications.(http://dx.doi.org/10.1016/j.clay.2016.07.001)
[39]. MucahitSutcu and SedatAkkurt, (2009), "The use of recycled paper processing residues in making porous brick with reduced thermal conductivity", Ceramics International, vol. 35, pp. 2625-2631.(doi:10.1016/j.ceramint.2009.02.027)
[40]. Nicolas Youssef, Andry Zaid Rabenantoandro, ZakariaDakhli, Christophe Chapiseau, FranciosWaendendries, FadiHageChehade and ZoubeirLafhaj, (2019), "Reuse of waste bricks: a new generation of geopolymer bricks", SN Applied science, pp 1:1252. (https://doi.org/10.1007/s42452-019-1209-6