An Overview of Current Research Trends in Geopolymer Concrete

Shaswat Kumar Das[1], Jyotirmoy Mishra[2], Syed Mohammed Mustakim[3]

[1]*Under Graduate Student, Department of Civil Engineering, Keonjhar, Odisha-758002, Odisha, India,*
[2]*Ph.D. Research Scholar, Department of Civil Engineering, VSSUT, Sambalpur, Odisha-768018, India*
[3]*Senior Technical Officer, Environment & Sustainability Department, CSIR-IMMT, Bhubaneswar, Odisha, India*

Abstract - *Cement industry may be considered to be one of the most polluting industries in present scenario due to large amount of carbon dioxide emissions leading to global warming. Sustainable utilization of various industrial waste products such Fly ash, Ground Granulated Blast Furnace Slag (GGBFS), Rice Husk Ash etc. as replacement of Ordinary Portland cement (OPC) in making concrete has definitely provided us an opportunity to lower carbon footprints. Geopolymer concrete is very helpful in providing us a new approach towards sustainability in which various industrial waste products can replace OPC as a binder completely. An overview of recent advances in geopolymer concrete has been presented in this paper in terms of fresh concrete properties: setting time and workability and hardened concrete properties: compressive strength and durability. Reviews specific to Fly ash based and GGBFS based geopolymer concrete have been highlighted. Research findings as mentioned in this paper successfully established geopolymer concrete as a better alternative to OPC based concrete.*

Key Words: **Geopolymer Concrete, Ground Granulated Blast Furnace Slag (GGBS), Ordinary Portland Cement (OPC), Rice Husk Ash (RHA), Workability, Sustainability**

1. INTRODUCTION

In the recent times, the greatest problem faced by industries is the disposal of its waste products such as fly ash, GGBFS, Rice Husk Ash, Silica fume etc. Land filling is not a desirable option because it not only causes huge financial burden on the foundries but also makes them liable for future environmental costs and problems associated with land filling regulations [1]. Efforts should be made on a larger scale to effectively utilize these waste materials. The construction industry can play an important role regarding this issue. Concrete usage has been on rise all around the world consuming cement as a binder material. However, the amount of carbon dioxide released during the manufacturing of OPC is in the order of one ton for every ton of cement produced [2]. It was reported that globally the production of cement contributed to about 5-7 % of the total carbon dioxide emissions into the atmosphere leading to global warming [3]. Considering the rapid growth of infrastructures worldwide in near future, the production, usage and the need for cement will increase at a higher rate which will have a severe impact on the environment. Therefore there is an urgency of developing alternatives to OPC based concrete. Geopolymer concrete is one of those alternatives which does not contain OPC as binding material rather it utilizes industrial waste products rich in silica and alumina such as fly ash, GGBFS, Rice Husk Ash etc. along with an alkaline solution for production of concrete having the strength and durability characteristics better than OPC based concrete with reduced carbon dioxide emissions. The objective of this review is to study the recent developments on geopolymer concrete by various researchers regarding properties such as compressive strength, workability, setting time, effect of alkaline solution content, curing methods to reach a better understanding of the concept and to encourage further developments.

2. GEOPOLYMERS AND GEOPOLYMER CONCRETE

The term "Geopolymer" was first introduced to the world by Davidovits of France resulting in a new field of research and technology [4]. Geopolymers are inorganic polymers which are synthesized by the reaction of solid aluminosilicate materials with alkali hydroxide/ alkali which consists of a three dimensional repeating unit of sialate monomer (-Si-O-Al-O-) [5]. It is well established that geopolymers have a chemical composition similar to zeolites but with an amorphous microstructure. Geopolymerization is geosynthesis (a reaction that chemically integrates minerals) that involves naturally occurring silico-aluminates [6]. Any pozzolanic compound or source of silica and alumina such as fly ash, GGBFS, Rice Husk ash etc .that is readily dissolved in the alkaline solution like Sodium/Potassium Hydroxide, Sodium/Potassium Silicate, acts as a source of geopolymer precursor species and thus lends itself to geopolymerization [7]. The alkali component as an activator is a compound from the element of the first group (Na, K) in the periodic table, so such material is also called as alkali activated aluminosilicate material [8]. Silicon and aluminium atoms react to form molecules that are chemically and structurally comparable to those building natural rocks [5]. The reaction process expels water which helps in improving workability in the geopolymer concrete mixtures [9]. Therefore, it offers wide industrial applications utilizing the waste materials such as fly ash, GGBFS, Rice husk ash etc. thereby providing better and greener alternatives in the construction industry as a green concrete. Unlike Ordinary Portland cement based concrete, Geopolymer concrete does not depend on C-S-H gel formation rather it facilitates three-dimensional polymeric chain matrix system to attain strength [10].

3. GEOPOLYMER CONCRETE MATERIALS

The major constituents of geopolymer concrete are source material and alkaline liquids other than the basic ingredients of concrete (viz. - coarse aggregates, fine aggregates, plasticizer/ superplasticizer etc.)

3.1. Source Materials

The source material for geopolymer concrete must contain an abundant amount of silicon (Si) and aluminum (Al) or both of it [11]. As the polymerization process needs both silicon and aluminum for the formation of the binder, it's better to choose a material which is both rich in aluminum and silicon.

The source material could be originated from nature or industry. The natural source materials are - kaolinite, volcanic ash, clays etc. whereas the industrial source materials are fly-ash, GGBS, Rice Husk Ash (RHA), palm oil fuel ash (POFA), Sewage Sludge Ash (SSA), silica fume etc. The choice of source material always depends on various factors which include - economy, availability, the type of applications, need of the end user etc. The excellent properties, availability and economy of fly ash and GGBS made them the most widely used source material for geopolymer concrete [2, 11].

Table – 1 Chemical composition and Loss on ignition of Fly ash and GGBS (Pradip Nath *et al.*)

Source materials	SiO2	Al2O3	Fe2O3	CaO	MgO	Na2O	K2O	SO3	P2O5	TiO2	LOI
Fly Ash	50	28.25	13.5	1.79	0.89	0.32	0.46	0.38	0.98	1.54	0.64
GGBS	32.46	14.3	0.61	43.1	3.94	0.24	0.33	4.58	0.02	0.55	0.09

3.2. Alkaline Liquids

The alkaline liquid used for the polymerization process is the combination of sodium or potassium based alkaline liquids. It is either the combination of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) or potassium hydroxide (KOH) and potassium silicate (K_2SiO_3) [11]. The sodium based liquids have wide acceptance because of its availability and performance [31].

4. PROPERTIES OF GEOPOLYMER CONCRETE

4.1. Fresh Concrete Properties

Workability and setting time

The workability and setting time are the most vital properties of the fresh concrete. Without knowledge of these properties, the concrete neither can be implemented nor commercialized. The workability of Geopolymer concrete depends on various factors viz.-water to Geopolymer solid ratio, fineness of the source material, the chemical composition of the source material, size and shape of the coarse aggregate etc. [11].

Though the rheological properties of Geopolymer concrete are different from cement concrete and there is no specific test to measure the workability of Geopolymer concrete hence slump cone method is used. The result of the slump cone method is acceptable and widely used in all the Geopolymer researches.

The workability of fly-ash and GGBS based Geopolymer concrete found by various scientists and researchers are discussed below.

Fly ash based Geopolymer concrete

Amer Hassan found a slump value of 126mm (max) for fly ash based geopolymer concrete. When he replaced the fly ash by slag by some percentage the workability started reducing. Addition of GGBS in ratio of 40% & 60% had resulted a slump value of 119mm & 115mm respectively [12]. With the higher ratio of alkali solution to fly-ash, the author observed higher workability in comparison to the lesser ratio, this may be due to the higher quantity of alkaline solution which contributes a little larger quantity of water to the same mix proportions [13].

The workability of the fresh geopolymer concrete decreases when the fly ash is replaced by rice husk ash. At the 25% and 30% replacement of fly ash with rice husk ash has very low workability [14].

GGBS based Geopolymer concrete

Parthiban Kathirvel *et al.* found a very good workability of GGBS based Geopolymer concret with the slump values of 160mm (max.) and 100mm (min.) at a ratio of 1.5 & 1.0 (GGBS-to-alkali activated solution (AAS) respectively. For all the mixes, NaOH concentration was 10M and the percentage of superplasticizer was 2% [15].

Pradip Nath & PK Sarker stated that the inclusion of GGBS in Geopolymer concrete reduces its workability and setting time. In their experiment, they found that the addition of GGBS in the Geopolymer concrete reduces the slump and flow value [12].

M.A. Salih et *al*. reported that the initial & final setting time of the POFA Geopolymer concrete reduces with the percentage increment of GGBS in the geopolymer concrete. The variation of the setting time is shown below in the chart.1 [22].

The GGBS based Geopolymer concrete achieved a great workability and setting time when some bio-additives (natural sugar etc.) were added to it. The slump value of controlled GPC (only GGBS) was varied between 135-140 mm whereas the bio-Geopolymer concrete had a slump value of 220mm [16].

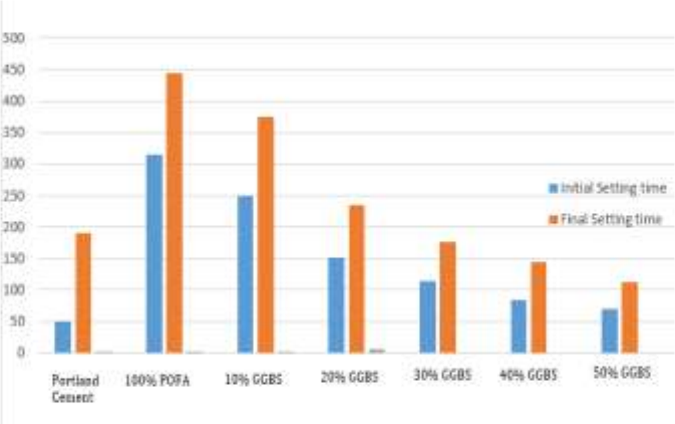

Chart.1 Initial and final setting time measured by Vicats apparatus (M.A Salih *et al.*)

4.2 Hardened Concrete Properties

The hardened concrete properties include a variety of properties which includes the mechanical properties viz.- strength, modulus of elasticity, drying shrinkage etc., durability properties, fire resistance etc.

In this article, the two major harden concrete properties (viz. - compressive strength & durability) of Geopolymer concrete has discussed.

Compressive Strength

Fly ash based Geopolymer concrete

Y. Park *et al.* reported that the maximum compressive strength of fly ash (class C, ASTM) based Geopolymer concrete was 42.5 Mpa where the concentration of NaOH was kept 14M [17].

The early compressive strength (7 days) of fly ash based geopolymer concrete was very high when 20% fly ash is replaced by OPC at 14M of NaOH. The maximum compressive strength obtained in 7 days was 64.39 Mpa [18].

A significant high early strength was achieved by fly ash based Geopolymer concrete using type-F fly ash and silica fume activated the solution. The maximum compressive strength was 105.2 MPa at the heat curing condition [19].

GGBS based Geopolymer concrete

J. Guru Jawahar *et al*. stated that the GGBS based Geopolymer concrete can achieve higher compressive strength as fly ash based Geopolymer concrete. They found a compressive strength of 57.6 Mpa after 28 days of curing [20].

Z. Chen *et al*. found a maximum compressive strength of 32.8 MPa of GGBS & Sewage Sludge Ash (SSA) based Geopolymer concrete [21].

The compressive strength of the geopolymer concrete had increased when the Palm Oil Fuel Ash (POFA) was replaced by GGBS. There was an increment of 65.45%, 60.3% & 62.7% in the compressive strength in 7, 14 & 28 days respectively [22].

P.K Nath *et al.* found a significant increment of compressive strength of the geopolymer concrete when fly-ash is replaced by GGBS. They have experimented with four mix designs of GPC with GGBS in their research Viz.- S00 (0% GGBS), S10 (10% GGBS), S20 (20% GGBS) and S30 (30% GGBS). The results are shown in the Chart-2 [12].

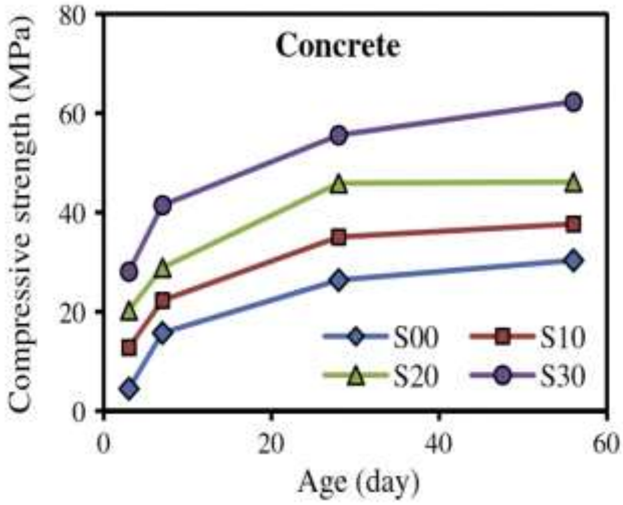

Chart.-2 The compressive strength of GPC with GGBS (P.K Nath *et al.***)**

Durability Properties

Sulfate resistance.

M.A.M. Ariffin *et al*. reported that geopolymer concrete has superior durability performance compared to OPC concrete in the sulfuric acid environment [24].

The GGBS based geopolymer concrete can last long in the sulfuric environment. From the experiment, it has been noted that the loss of weight of GGBS based Geopolymer concrete is very less [20, 31].B. Vijaya Rangan stated that heat-cured low-calcium fly ash based geopolymer concrete has an excellent resistance to sulfate attack. There was no damage to the surface of test specimens after exposure to sodium sulfate solution up to one year [11].

Chloride resistance

Joshi *et al.* found that heat cured fly ash based geopolymer concrete showed excellent resistance to chloride attack when exposed sodium chloride solution up to 90 days [28]. Sanni *et al.* confirmed improved resistance for chloride permeability and low rate of corrosion risk level through RCPT (Rapid Chloride Penetration Test) where maximum and minimum charges passed for 28 days was 1968 and 1548 coulombs for M30 and M40 grade of Geopolymer concrete [27].
K. Pasupathy *et al.* found that the low calcium fly ash based geopolymer concrete has less resistance against the saline environment as compared to the OPC concrete. They stated this may be due to the high porosity of the GPC than the OPC concrete which allowed the chloride ions to penetrate inside the concrete [23].

5. FACTORS AFFECTING GEOPOLYMER CONCRETE

5.1 Curing Temperature and Methods

Heat curing, ambient temperature curing and shade curing are the methods of curing adopted in Geopolymer concrete. The heat curing is best suited for precast industries but it becomes a limitation to the application of Geopolymer concrete in in-situ castings [12].

The heat curing at high temperature (60°C) has a significant effect on the early strength gain of the fly ash based geopolymer concrete. The development of strength overage up to 56 days after heat curing is not remarkable [2].In case of the ambient curing, the strength gaining process is similar to OPC concrete, with age the strength of the concrete increases [12].

5.2 Alkali Liquid Ratio (R)

Khalid Bashir reported that there is an increase in compressive strength of geopolymer concrete when the ratio of alkaline liquid (Sodium silicate/Sodium Hydroxide) is increased [26].Hardjito *et al.* also reported that increasing the alkaline liquid ratio from 0.4 to 2.5 with the same concentration of Sodium Hydroxide resulted in an increase in compressive strength [25].

5.3 Molarity of NaOH

The compressive strength of the geopolymer concrete is increased with the increase of the molar concentration of the sodium hydroxide (NaOH) of the alkaline liquid [11, 32].

5.4 Water-to-Geopolymer Solid Ratio

In this parameter, the total mass of water is the sum of the water present in the sodium silicate solution, the amount of water used in the making of the sodium hydroxide solution, and the extra water, if added during mixing. The mass of geopolymer solids is the sum of the mass of source materials, the mass of sodium hydroxide solids used to make the sodium hydroxide solution, and the mass of solids present in the sodium silicate solution (i.e. the mass of Na_2O and SiO_2) [6].

From the experimental results, the compressive strength of geopolymer concrete decreases as the water-to-geopolymer solids ratio increases [20].

5.5 Particle Size of the Source Material

The particle size of the source material has an immense effect on the strength of the geopolymer concrete is stated by L.N. Assi *et al.* For instance, when the finer particle fly ash is used then the compressive strength is increased considerably [19].The ultrafine fly ash has a wide impact on geopolymer concrete properties.
The addition of ultrafine fly ash improves the compressive strength, reduces the porosity and in other hand it reduces the workability & setting time of the concrete [30].

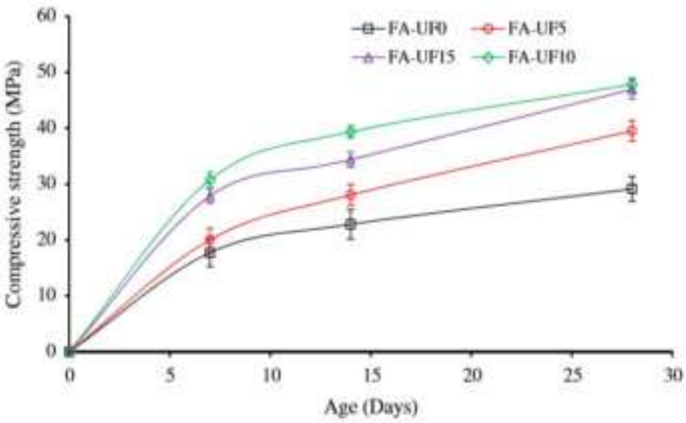

Chart-3 Compressive strengths of the fly ash–only geopolymer with ultrafine fly ash (Partha Sarathi Deb and Prabir Kumar Sarker)

6. CHALLENGES IN GPC

Though Geopolymer concrete has shown remarkable performance and gained importance during last decade regarding strength, durability and academic researches, there are certainly many challenges which need to be brought into notice of researchers. Some of the challenges are mentioned below.

- There is a need for generalisation of water/solid ratio which will make it user-friendly.
- The investigations regarding corrosion of reinforcement and bond behaviour are not sufficient to establish its wide acceptance.
- There is no proper code standards and regulations yet which hinders in the implementation of its various applications.
- Use of superplasticizers has not been investigated properly in terms of grade of concrete.

- Research data regarding strength and properties of geopolymer concrete under ambient curing conditions needs to be encouraged at a larger level for better understanding.

7. CONCLUSION

Based on the discussion, it is concluded that geopolymer concrete provides tremendous potential to be used as a construction material in the coming future. Setting time, workability and durability characteristics of Geopolymer concrete proved to be better than OPC based concrete. However certain limitations need to be overcomed which will lead to a better acceptance of geopolymer concrete amongst infrastructure owners and managers, designers, contractors, researchers, governmental decision makers, and the society as a whole.

REFERENCES

[1] Wiles CC Standard handbook of hazardous waste treatment and disposal. McGraw Hills, New York (1988), p7.85
[2] B.V. Rangan, Fly Ash-Based Geopolymer Concrete, University of Technology, 2008.R. Nicole, “Title of paper with only first word capitalized,” J. Name Stand. Abbrev., in press.
[3] B.C. McLellan, R.P. Williams, J. Lay, A. Van Riessen, G.D. Corder, Costs and carbon emissions for geopolymer pastes in comparison to ordinary Portland cement, J. Cleaner Prod. 19 (9) (2011) 1080–1090.
[4] Vignesh P., Vivek K., An Experimental Investigation on Strength Parameters of Flyash Based Geopolymer Concrete with Ggbs, International Research Journal of Engineering and Technology (IRJET) Volume: 02 Issue: 02, p135-141.
[5] Duxon P, Fernandez-Jiminez A, Provis JL, Luckey GC, Palomo A, Van Deventure JSJ. Geopolymer technology: the current state of the art. J Mater Sci 2007; 42:2917–33.
[6] Hermann E, Kunze C, Gatzweiler R, Kiebig G, Davidovits J: Proceedings of Geopolymer (1999), p 211.
[7] Xu H, Van Deventer JSJ, International Journal of Mineral Processing (2009) 59:247
[8] Xiong CJ, Ban CH, Pei X, Fang Z, International workshop on sustainable development and concrete technology, Beijing (2004), p 299.
[9] Komnitsas KA., Potential of geopolymer technology towards green buildings and sustainable cities,International conference on green buildings and sustainable cities, procedia engineering, vol. 21; 2011: p.1023–32.
[10] Van Jaarsveld JSG, Van Deventer JSG, Lukey GC, Journal of chemical Engieering (2002), 89:63
[11] B. Vijaya Rangan. Geopolymer concrete for environmental protection. The Indian Concrete Journal, April 2014, Vol. 88, Issue 4, pp. 41-48, 50-59
[12] Pradip Nath & Pk sarker, Effect of GGBFS on setting, workability and early strength properties of fly ash geopolymer concrete cured in ambient condition, Construction and Building Materials 66 (2014) 163-171
[13] Sourav Kumar Das1, International Journal of Engineering & Technology, 7 (2.31) (2018) 196-198)
[14] Mohamed Usman M.K.1, Senthil Pandian M.2, Civil Engineering Systems and Sustainable Innovations ISBN: 978-93-83083-78-7
[15] K.Parthiban et.al / International Journal of Engineering and Technology (IJET), ISSN : 0975-4024 Vol 5 No 3 Jun-Jul 2013
[16] A. Karthik, K Sudalaimani, C.T Vijayakumar, Investigation on mechanical properties of fly ash-ground granulated blast furnace slag based self-curing bio-geopolymer concrete, Construction and Building Materials 149 (2017) 338–349
[17] Yeonho Park et al. Compressive strength of fly ash based geopolymer concrete with crumb rubber partially replaced sand, Construction and Building Materials 118 (2016) 43–51
[18] Ankur Mehta & Rafat Siddique, Sulfate acid resistance of fly-ash based geopolymer concrete, Construction and Building Materials 150 (2017) 817–824
[19] Lateef N. Assi et al. Investigation of early compressive strength of fly ash based geopolymer concrete, Construction and Building Materials 112 (2016) 807–815
[20] J. Guru Jawahar1, D. Lavanya1, C. Sashidhar 2International Journal of Research and Scientific Innovation (IJRSI) |Volume III, Issue VIII, August 2016|ISSN 2321–2705
[21] Zhen Chen, Jiang-Shan Li, Bao-Jian Zhan, Usha Sharma, Chi Sun Poon, compressive strength and microstructural properties of dry-mixed geopolymer pastes synthesized from GGBS and sewage sludghe ash, Construction and Building Materials 182 (2018) 597–607
[22] Moslih Amer Salih et al., Development of high strength alkali activated binder using palm oil fuel ash and GGBS at ambient temperature, Construction and Building Materials 93 (2015) 289–300
[23] Kirubajiny Pasupatha, Marita Berndta, Jay Sanjayana, Pathmanathan Rajeeva, Didar Singh Cheema, Durability of low-calcium fly-ash based geopolymer concrete culvert in saline environment, Cement and Concrete Research 100 (2017) 297–310.
[24] M.A.M. Ariffin, M.A.R.Bhutta, M.W. Hussin, M. MohdTahir, N. Aziah, Sulfuric acid resistance of blended ash geopolymer concrete, Constr. Build. Mater. 43 (2013) 80–86
[25] Hardjito, D. and Rangan, B. V., Development and Properties of LowCalcium Fly Ash-based Geopolymer Concrete, Research Report GC1, Faculty of Engineering, Curtin University of Technology, Perth, 2005
[26] Khalid Bashir, Fly ash Based Geopolymer Concrete, International Conference on Advances in Engineering & Technology (2014), p19-23
[27] Shankar H. Sanni and R.B. Khadiranaikar, Rapid Chloride Penetration Test on Geopolymer concrete, International Journal of Earth Sciences and Engineering (2012), Vol. 5, Issue 6, p 1652-1658

[28] Bhagia Maria Joshy, Dr. Mathews M Paul, Resistance to sodium sulphate and sodium chloride attack of fly ash based geopolymer concrete, Transactions on Engineering Services (2014), Vol. 2, Issue 10, p 22-27

[29] Amer Hassan,Experimental Study of Fly Ash Based Geopolymer Concrete, International Journal of Advanced Earth Science and Engineering 2018, Volume 7, Issue 1, pp. 635-648

[30] Partha Sarathi Deb and Prabir Kumar Sarker, Effects of Ultrafine Fly Ash on Setting, Strength, and Porosity of Geopolymers Cured at Room Temperature, .DOI:10.1061/(ASCE)MT.1943-5533 .0001745. © 2016 American Society of Civil Engineers

[31] Shaswat Kumar Das, Jyotirmoy Mishra and Syed Mohammed Mustakim, Rice Husk Ash as a Potential Source Material for Geopolymer Concrete: A Review International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 7 (2018) pp. 81-84

[32] A Review on Geopolymer Concrete: A Green Concrete Prakul Thakur, Khushpreet Singh, International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056, p-ISSN: 2395-0072 Volume: 05 Issue: 05 | May-2018

BIOGRAPHIES

Shaswat Das is currently pursuing his bachelors at Govt. College of Engineering, Keonjhar, Odisha, India. He has published one international journal and four international & national conference papers in the field of concrete technology. Now he is working on a project titled "Rice Husk Ash based geopolymer concrete" sponsored by TEQIP-III, Govt. of India at CSIR-IMMT, Bhubaneswar.

Jyotirmoy Mishra is a PhD Research Scholar at VSSUT, Burla,Odisha, India. He has obtained his bachelors and masters from KIIT University, Bhubaneswar, Odisha, India. He is working on geopolymer concrete since his masters and being associated with various research projects in the field of geopolymer concrete. He has published one international journal and many national and international conference papers. He is a member of the Institute of Engineers, India.

Dr. Syed Mohommed Mustakim is a senior technical officer at CSIR-IMMT, Bhubaneswar, Odisha, India. He has more than sixteen years of experience in the field of cement, brick manufacturing and concrete technology. He has two patents and several international and national publications in reputed peer reviewed journals.