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Fly Ash/Slag Geopolymer Technology Development and Deployment in Construction and Infrastructure Industry: India's Perspective

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Abstract: *India is fast shifting from the image of agrarian economy to industrial economy. While the total Indian Economy is of 152.51 lakh Crore rupees, the construction sector contribution alone to the national GDP is 10,64,068 Crore rupees. Construction and infrastructure industry exerts a lot of environmental pressure by consuming natural assets and the cement production is energy intensive. Cement that production is responsible for around 10% of global CO_2 emissions. Like other countries with emerging economies, India faces the dual challenge of reconciling its rapid economic growth with a pressing need to address climate change. This paper addresses on the innovation in the Low carbon foot print material, Geopolymers, alternatives to Portland cement that show similar mechanical properties that provide new incentives to address the climate change. In India, geopolymer technology is still confined at laboratory research and development levels. Beyond research, this new material technology has to be crossed in transition from scientific discovery from laboratory to innovation and wide scale deployment. This paper centers on the feasibility of geopolymer production from the industrial by products: Fly ash /Slag from resources available and its application acceptance in India for the present and the future. The key drivers for uptake of geopolymer technology are the need of stakeholder's initiative, development of knowledge base, technical/equipment providers and practical standards. Strategy and implementation plan at national level is required for promotion of green materials and replacement of high embodied energy materials with lower one.*

Keywords: *Geopolymer, Fly ash, Indian economy, CO_2 emission, construction industry*

1. Introduction

Construction and infrastructure industry sector is a key driver for the Indian economy and is highly responsible for propelling India's overall development and enjoys intense focus from Government for initiating policies. In 2016, India jumped 19 places in World Bank's Logistics Performance Index (LPI) 2016, to rank 35th amongst 160 countries. The GDP contribution of the construction sector is estimated to grow at a Compound Annual Growth Rate (CAGR) of 9.5-10 percent till 2022, especially retail housing and commercial real estate is expected to increase at a CAGR of 11.2 per cent in the period FY2008-2020 [1]. Indian construction development sector has received Foreign Direct Investment (FDI) equity inflows to the tune of US$ 24.28 billion in the period April 2000-December 2016 [2,3] with a expected market in real estate to touch US$ 180 billion by 2020. The housing sector alone contributes 5-6 per cent to the country's Gross Domestic Product (GDP). In India as elsewhere in the world, the embodied energy of the building sector is increasing exponentially due to the high rate of construction (10-15%) and poor choices of materials. Greening of the building sector requires market push for appropriate green materials to be made available at affordable costs. It is therefore, imperative that there is an urgent need to look for and develop alternative materials which are more environment–friendly.

This paper focuses on new low carbon foot print materials, namely, Geopolymers derived from industrial wastes as an alternative binder to Portland cement in construction that integrate sustainable waste management.

2. Portland Cement Demand in India

Indian Cement Industry, the second largest cement producer in the world and cement production is estimated to reach between 78 Mt (low demand scenario) and 1360 Mt (high demand scenario) by 2050, with annual production rate increase at almost 10% per year. The biggest demand is in housing sector accounting for 67%, 13% in Infrastructure Development, around 11% to Commercial construction and 9% to Industrial Construction. Government of India plans to increase investment in infrastructure to the tune of US$ 1 trillion and increase the industry's capacity to 150 MT during 12th year plan. The Union Budget proposed to assign infrastructure status to affordable housing projects and facilitate higher investments and better credit facilities, in line with the government's aim to provide

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housing for all by 2022. Therefore cement demand is in line with accelerated rapid urbanization due to population growth by almost 40% between 2010 and 2050 (1.2 billion to 1.7 billion). To meet the rise in demand, cement companies are expected to increase their capacity and attracting Foreign Direct Investment (FDI)[4,5,6].

To produce one ton of Portland cement, 1.6 tons of raw materials: lime stone and clay are needed and the extraction of raw materials from the earth is 20% faster than the earth replenishing it, so raw materials consumed in 12 months will take 14.4 months to be filled back. The cement industry is held responsible for some of the CO_2 emissions, because the production of one ton of Portland cement emits approximately one ton of CO_2 into the atmosphere and approximately, the contribution of cement industry to the CO_2 emissions is about 5–7% of the global CO_2 emissions. There is always a dynamic link between energy consumption, economic growth and green house gas emissions.

2.1. Green house gas emission status in India

The most current projections of India's GHG emissions has been released by the Government of India's Planning Commission in the Interim Report of the Expert Group on Low Carbon Strategies for Inclusive Growth (Planning Commission, 2011a) and estimates the projected GHG emissions for India by 2020 as given in Fig.1 [7,8,9,10]. The major carbon intensive industrial sector was considered in terms of combustion-related carbon, mostly fossil fuel energy and coal power generation whereas; in non-combustion related carbon is from steel, cement industry.

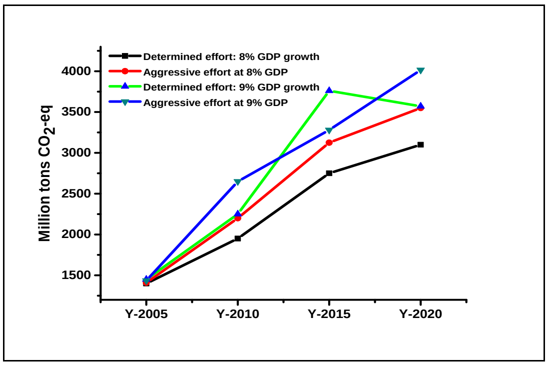

Fig.1. *India's Projected Total GHG Emission By 2020 (Non Agricultural Only) (Source: Planning Commission, 2011 a)*

Two scenarios have been considered in which the Determined Effort scenario assumes that policies already in place or planned are pursued vigorously and implemented effectively up to 2020. However, this scenario will require continuous upgrading of technology as well as financing from both public and private sources. Whereas, another scenario the Aggressive Effort related to the introduction and implementation of new policies, new technology, additional finance, and increased efforts by the private sector. Therefore carbon mitigation policy requires intensive efforts on development of alternate green technology especially in construction and infrastructure industries.

3. Scope of the study

Portland cement which is widely used around the world and the cement industry has a history of more than 180 years. Hence knowledge has built up about its processing, long-term behavior, and limestone, from which it is derived, performance characteristics and standards/code of practice. Considering these factors, the market position of Portland cement is strong. However, the inherent disadvantage of high carbon content remains difficult to overcome. To reduce CO_2 emissions, there are four technological key levers such as use of Alternative Fuels and Raw materials (AFR), improvement in Thermal and Electrical Energy efficiency, reduction in Clinker to Cement Ratio, and application of newer technologies that have been identified and considered to be the basis of a low-carbon technology roadmap for the Indian cement industry [launched in February 2013.] [11,12,13]. In order to reduce amount of usage of Portland cement in concrete, development of geopolymer, an inorganic alumino silicate derived from industrial wastes fly ash/slag produced at ambient temperature is an important vision towards the production environmental friendly concrete.

4. Geopolymers

4.1 Geopolymerization process

Geopolymers are generally viewed as subset of Alkali Activated Materials (AAM), promoted as a component of the current and future toolkit of 'sustainable cementing binder systems'. Where the binding phase is almost aluminosilicate which are highly coordinated [14,15,16]. In this type of binder, binding gel is usually low in calcium with high alumina content, so as to form pseudo zeolitic framework rather than formation of calcium silicate hydrate [17,18,19]. One of the most important raw materials is Fly ash, a finely sized by-product of coal combustion, which is recollected at energy plants in electrostatic bags. In addition to Fly ash, other additives such as Ground Slag, Kaoline, Metakaoline, Rice husk ash, Palm oil ash, Volcanic ash, Bolus and CalcinedBolus were applied as a basic material of geopolymers. These alumino silicate precursors, vitreous compounds convert into a compact materials characterized by cement like binding property through alkali mediated chemical process. These Geopolymeric binder offers superior properties compared to Portland cement in terms of corrosion and high temperature resistance (above 1,000 _C) and lower carbon footprint.[20].

In late 1970s French, Chemical Engineer, Davidovits reignited the interest in this area and the inorganic materials obtained from the chemical reaction of alumino-silicate oxides mostly Metakaolin with alkali silicates, yielding polymeric Si-O-Al bonds. Davidovits described these inorganic materials as Geopolymers and patented numerous alumino silicate formulations for niche applications [21]. Several reports can be found in the literature on the formulations, properties and applications [22,23].

4.2 Geopolymer Technology Development and Deployment: Global Scenario

Alkali Activated Materials (AAM), was first introduced by the Belgian civil engineer, A O Purdon in 1940 called as Slag-Alkali Binders [24]. Glukhovsky from the institute in Kiev, USSR, focused predominantly on alkali-carbonate activation of metallurgical slags and demonstrated viability of the technology at scale [25]. Several reputed groups in Czech Republic working on commercial scale level in the production of fly ash-slag blends for fire resistance materials and waste immobilization. [26]. Chinese researchers developed a range of materials throughout the 1980s and subsequently, many of which are based around the development of sulphate-containing phases for strength development. The reuse of industrial wastes has been encouraged by Chinese government and taxation policy. The products with content of industrial wastes more than 30% can be sold tax free. Hence research and development in AAMs chemistry and manufacture are good in China proving the value of this technology on a worldwide basis [27,28,29]. Alkali activation research in the Western world was quite limited until the 1980s, as highlighted in a review by Roy [30].

The United States Army published a report discussing the potential value of alkali activation technology in military situations, particularly as a repair material for concrete run ways. It was prepared in conjunction with the commercial producers of an alkali-activated binder which was at the time sold under the name Pyrament. Since then, alkali activation research has grown dramatically in all corners of the globe, with more than 200 active research centers (academic and commercial) now operating worldwide [31-41]. Strong research and scientific foundations for the understanding of AAMs chemistry and technology developed in Spain by Palomo, Puertas and groups worked for durability of matrices mechanism of reactions, explored various additives in the system. Eduardo Torrajo Institute for construction science worked for sustainable construction materials [42]. Similar works also progressed in UK focused on composites and coatings [43,44]. Advance in Fly ash utilization chemistry and engineering properties related works at Lousiana Tech University initiated for the uptake of AAM technology in force [45].

In Australia, the commercial implementation of geopolymer technology is currently being driven by multiple teams operating in different parts of the country. Curtin University and the Centre for Sustainable Resource Processing, based in Perth, have made advances in this area over the past decade and implemented at site conditions [46]. Zeobond, a Melbourne-based company, developed its own production facilities in 2007 and now supplies its concrete E-Crete™, to major civil infrastructure projects viz: freeway-expansion works and bridge construction and repairs under license. E-Crete™ utilises for its binder a blend of fly ash/ ground blast furnace slag, with combinations of proprietary alkaline activating components which are tailored for specific raw materials and products [47]

In 2011, Queensland based Wagner CFT Manufacturing Pty Ltd., introduced Earth Friendly Concrete (EFC) considered a giant lead towards low carbon concrete. EFC has been trialed in various projects and performed better than OPC in applications which include Drive Way Pavement, Footpaths, Structural Bridge Beams, Precast Retaining Walls and Boat Jetties. World's first geopolymer building is in Queensland University, Australia. A detailed report on geopolymer precast concrete products includes Sewer Pipes, Railway Sleepers, and Wall Panels on a commercial scale by Gourley and Johnson [48]. Reinforced geopolymer concrete sewer pipes with diameters in the range from 375 mm to 1800 mm have been manufactured using the facilities to make similar pipes using Portland cement concrete. The other potential application of geopolymer concrete is rigid road concrete components such as Underpasses, Traffic Inland Roads, Paved Access Street and Precast Components of Roads etc. One of the successful implantation of geopolymer road is VicRoads using structural geopolymeric concrete using 55 Mpa E-Crete and about 180 Precast panels across Salmon Street Bridge in Port Melbourne, Victoria, Australia that showed the entire process of commercialization of geopolymeric concrete in reality [49]. Recently**,** Brisbane West Well Camp Airport (BWWA) is Australia's first green field public airport to be built in 48 days and fully operational with commercial flights [50]. This project marks a very significant milestone in 'Engineering the geopolymer technology' [51].

In India, Geopolymer concrete technology is still mostly confined at laboratory levels, and gaining momentum to apply in construction sector. Academic institutions, CSIR R & D laboratories have been put their efforts for popularizing this technology in commercial arena. [52,53,54,55]. The durability of the geopolymer derived from fly ash/slag has been studied and ecological advantages of using these industrial by products in the geopolymer production has been established. [56]. Despite enormous research publications in the field of geopolymer technology (around 450 -500 articles in Scopus indexed journals) covering chemistry at microscopic level and material properties for concrete making. Only 10% of reported literature is on structural engineering and construction aspects of geopolymer concrete. Very few reports dealt with structural design aspects and constructional issues.

4.3 Trends of Fly ash /slag utilization potential in Geopolymer production: Indian scenario

Up scaling of geopolymer production and their utilization mainly depends upon the availability and management of primary resources and hence economic viability has been looked into the supply chain of raw materials. The manufacturing process of Flyash/slag based geopolymer is schematically represented in Figure. 2.

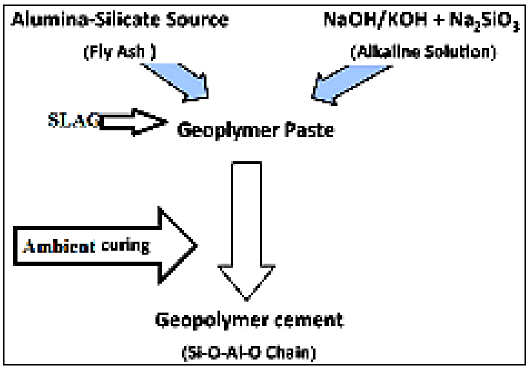

Fig 2. *Geopolymer Manufacturing Process*

Coal is mainstay of Indian energy system and ranked in third place in the world both in production and consumption of coal. It is the country having the fourth largest coal reserves after the United States, Russia and China, and expected to meet about 42 per cent of energy demand by 2035. [57,58]. Since wide scale coal firing for power generation, many millions of tons of ash in the form of Flyash, pond ash and related by-products have been generated. In the financial year 2016-17, it is expected to increase the production of fly-ash around 300-400 MT. Further, the large-scale storage of wet fly ash in ponds takes up much valuable agricultural land approximately (113 million m^2), that may result in severe environmental degradation in the near future [59]. Though fly ash is considered as the world's fifth largest raw material resource, its % utilization of fly ash during the year 2015-16 was only 60.0 %. It was estimated that 45% of fly ash in India was used for cement production, construction of roads and brick manufacture [60]. The thermal power generation, coal consumption and ash generation as projected by GOI has been given in Table. 1.

Table 1. *Coal Power and Fly ash generation*

Year	Thermal power generation in (mW)	Coal consumption (mT)	Ash generation (mT)
1995	54,000	200	75
2000	70,000	250	90
2010	98,000	300	110
2020	1,37,000	350	300-450

The present utilization of Fly ash is shown in the Figure 3.

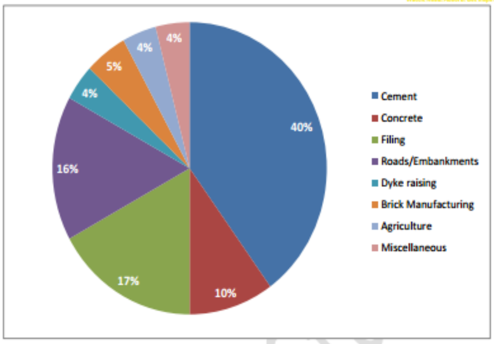

Fig 3. *Fly ash utilization in India*

It was found that utilization of fly ash in cement and concrete has limitations due to mismatch between growth in consumption of cement and co-generation of fly ash. The percentage of fly ash blended cement has already reached to 67% of total cement production in India and is likely to remain within the range of 65% to 70% in future years [61]. Therefore 100% utilization of fly ash as envisaged by Ministry of Environment and Forest (MOEF) does not appear to be practically feasible. Hence development and deployment of geopolymer material production from fly ash is considered to be more positive aggressive strategy of fly ash utilization.

Slag from steel plant is the raw materials used along with fly ash for geopolymerisation reactions, its availability for continuous production to be estimated. India is the 3rd largest producer of crude steel in and the 2nd largest producer of sponge iron in the year 2016. The National Steel Policy (NSP) had envisaged steel production to reach 110 million tonnes (mt) by 2019 – 20. It is also assumed that per capita consumption of steel in India may peak at an average of 400 kg per in 2050. Combining this data with the population projection for India by the UN (1.5 billion in 2050), reaching a peak consumption of 600 million tonnes (MT) by 2050 [62,63].

Considering the steel production, estimation of wastes generated from various process have been done. Indian plants dispose of 0.5 tonne of solid waste for one tonne of steel production, which is five times the global practice. Mostly it depends upon the type of furnace used in plants. In the case of coal DRI-based plants dispose of more than 1.2 tonnes of waste for every tonne of steel produced, and gas DRI-EAF plants dispose of the lowest amount of waste, around 0.25 tonne. Slag generation in Blast Furnace as per international practice is around 250 kilograms per tonne of hot metal (kg/thm). In India, it is between 300 and 350 kg/thm. This higher slag arising in blast furnace is due to the poor quality of raw materials. Slag wastes are mostly used for rail or road ballast and for making pavements, largely remain unutilised and huge mountains of this slag are found around the plants. However, slag granulation of increased their utilization in cement to level of 80% and sold as slag cement. However, the process based slag is widely varied in their chemical compositions and their utilization target is still to be achieved.

The other raw material required for production is alkali in the form of sodium hydroxide and sodium silicate of appropriate combination. The market size of sodium silicate is mainly in detergent and soap market and utilization in construction industry is almost negligible. Therefore, the production technology of geopolymers derived from raw material fly ash/GGBS in India is more optimistic and best method of waste valorization technology.

4.4 Construction applications of Geopolymers: Labcrete to real life process

Translation of geopolymeric research into practice may be too slow compared with that of Portland cement concrete. As the history goes, it was used in the time where difficulty faced on the use of timber and steel and its large scale applications took nearly 140 years of incubation period. In a similar way geopolymer technology will be compelled to use because of its superior performance and sustainability credentials. Over the years large scale industrial trials engaging in the manufacturing of alkaline cements and use of alkaline cement concrete structural members in construction applications especially in Ukrain, France, Poland, Australia, Russia and UK . [64-70]. The technology developed in this areas are: (i) Geopolymer concrete technology similar to conventional concrete technology (ii) Geopolymer cement technology in which products are packaged in bags for subsequent use (iii) Geopolymer Pre casting technology in which pre cast elements are made from alkaline concretes/cements. The real life applications during the last 10 years are notable and the field performance details till the year 2015 has been listed by J.G.Sanjyan. [71]

4.5 Codes and Standards

Regarding standards and code of practice on geopolymer concrete usage around the world is limited. Slag based alkaline cements commercialized in the former USSR and comprehensive codes and standards are in practice [72]. Subsequently in Ukrain (Ukrain DSTU) approved specifications for various types of cements like European standard EN-196.7-181:2009. The standard applies to concrete manufacturer for ordinary use [73]. US standard ASTM1157 (121) covers the performance specifications of hydraulic cements for both general and specific applications [74]. British standard recently published on Alkali activated cementitious materials and concrete specification as PAS8820:2016 [75]. RILEM technical committee (TC224-AAM) compiled the works related to geopolymeric prime materials, cements, concretes, structures and test procedures of various types of alkaline cements for the promotion and uptake by stakeholders. The real life construction of geopolymer largely made in Australia due to Zeobond Pty Ltd.,in Victoria and Wagners in Quennsland. Appropriate guidelines used are: Australian standards AS 3600,1379,3972 wherein geopolymer concrete is permitted to use. Handbook on ' Geopolymer and high volume fly ash concrete for pavements' prepared by Berndt M A &Chadburn.G [76]. It provides reference to geopolymer concrete usage. Vic-Road authority is considered to be a pioneer in providing geopolymer concrete use in paving of roads (Andrews-Phaedonos, 2013) [77].

4.6 Potential of scalability of Geopolymer industry in India

Based on the highpoints of applications and research efforts across, this study made prior assessment for widespread use of geopolymer in India. Surveying about these new materials among academic/engineering consultants and material supplier conducted. Input on selected parameters in the form of questionnaire has been collected from the representative group. Preliminary results indicated that the major barrier in the applications is mainly lack of awareness of the materials and available technology. Only few of the respondents were found to be knowledgeable about this new technology. Respondent clearly identified that there was no simplified tips for engineers to use Geopolymer technology on site that are still under development and hence, they felt that only well informed and technical personnel should get involved in production and usage of Geopolymers in order to get desired level of performances of structures built with Geopolymers. Other aspects about the material supply reliability, processing parameters and cost economics.

The pilot study results demonstrate that there are important issues and concern needs to be addressed for geopolymer in large scale use. Table 2 reveals the information about identified important influencing parameters, barriers for uptake and possible solution, and areas for development needed.

5. Conclusions

Paper describes briefly about the construction industry, supply- demand of cement in Indian context. A brief history of geopolymers and highlights of research activities in this area have been presented. Despite the current status and wide acceptance of Portland cement concrete, the desirable properties of geopolymers, commercial R & D activities around the world suggest that deployment of geopolymer technology is poised for significant progress in India.
The production of geopolymers derived from industrial by products Fly ash/slag produced at ambient temperature mainly on the objectives of sustainability because of the maximum utilization of industrial wastes, simple and lower energy intensive process technology that creates incentives for significant emission mitigations. To create a market

trend for geopolymer industry, technological, financial and institutional barriers and solutions to overcome have been discussed to achieve wide acceptance and application.

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References

[1] CW, 2015. The Skill Gap, Hiranandani, N. Construction World, Jan-2015.

[2] Economic-Survey: FY 2010-11, 2015-16., 2016-17

[3] https://www.ibef.org/industry/real-estate-india.aspx.

[4] Reports by india brand equity foundation on real estate,cementhttps://www.ibef.org/download/Cement-June-2017, www.ibef.org. DIPP, TechSci Research

[5] Cement Technology Roadmap 2009 (International Energy Agency and World Business Council of Sustainable Development, 2009); http://go.nature.com/jQLKa7 .The technology papers at www.wbcsdcement.org/technology

[6] Cement Statistics and Information 2015 (United States Geological Survey, 2015); http://go.nature.com/IqaKnt.

[7] Pahuja, N., N. Pandey, K., Mandal, and Bandyopadhyay, C. 2014. “GHG Mitigation in India: An Overview of the Current Policy Landscape.” Working Paper. Washington, DC: World Resources Institute. Available online at http://www.wri. org/publication/ghg-mitigation-ind-policy.http://planningcommission.nic.in

[8] Mita Bhattacharya, HooiHooi Lean and Sankar Bhattacharya, Economic Growth, Coal Demand, Carbon Dioxide Emissions: Empirical Findings from India with Policy Implications Discussion Paper 47/14 , ISSN 1441-5429 Department Of Economics, Monash University.

[9] Govindaraju, V.G.R., Tang, C.F. 2013. The dynamic links between CO_2 emissions, economic growth and coal consumption in China and India. Applied Energy.104:310–318. DOI: http://dx.doi.org/10.1016/j.apenergy.2012.10.042

[10] Technology Roadmap: Low carbon technology for the Indian Cement Industry’ (WBCSD, IEA, February 2013).

[11] Low Carbon Strategies for Inclusive Growth: An Interim Report’ (Planning Commission, Government of India, May 2011.

[12] Fonta, P., Mishra,A.K.,Chaturvedi,S K.,Pahuja,A.,Twigg,C., Trudeau,N., Tam,C ., KiranAnanth, P V.,2011. Reduction Potentials In The Indian Cement Industry – A Way Forward. WBCSD CSI Technical Papers.

[13] Provis, J L., Bernal, S A. 2014.Geopolymers and related alkali-activated materials, Annu. Rev. Mater. Res. 44: 299–327.DOI: https://doi.org/10.1146/annurev-matsci-070813-113515

[14] Provis, J L., Palomo, A., Shi, C.2015. Advances in understanding alkali-activated materials, Cem. Concr. Res.78A: 110–125.

[15] Provis, J L., van Deventer.J S J. 2014.Alkali-activatedMaterials: State-of-the-Art Report, RILEMTC 224-AAM, Springer/RILEM, Dordrecht.

[16] Shi, C., Qian, J. 2000. High performance cementing materials from industrial slags - a review,Resour. Conserv. Recycl. 29:195–207.

[17] Shi, C., Fernández-Jiménez, A., Palomo, A. 2011. New cements for the 21st century: thepursuit of an alternative to Portland cement, Cem. Concr. Res. 41:750–763.

[18] Shi, C., Krivenko, P V., Roy, D M. 2006. Alkali-activated Cements and Concretes, Taylor & Francis, Abingdon, UK.

[19] Wang, S D., Pu, X C., Scrivener, K L., Pratt, P L. 1995.Alkali-activated slag cement and concrete: a review of properties and problems, Adv. Cem. Res. 7: 93–102.

[20] J. Davidovits, (2015)Geopolymer: Chemistry and Applications, 4^{th} edition, Institut Géopolymère, Saint-Quentin, France.

[21] Davidovits, J. Patents : Tailored geopolymer composite binders for cement and concerte applications; USA WO/2010/085537 b)Pervious concrete comprising of geopolymerisedpozzolianic ash binder USA WO/2010/030560 28/24. c)Geopolyer concrete and method of preparation and casting Austraila. WO/2005/049522. d)Geocomposite US/4349386; GEOPOLYMER INSTITUTE : www.geopolymer.org.

[22] Van Deventer, J S J., Provis, J L., Duxson, P. 2012. Technical and commercial progress in the adoption of geopolymer cement, Miner. Eng. 29:89–104.

[23] Duxson, P., Fernández-Jiménez, A., Provis, J L., Lukey, G C., Palomo, A., Deventer,J S J.2006. Geopolymer technology: the current state of the art, J. Mater. Sci. 42:2917–2933.

[24] Purdon, 1940. The action of alkalis on blast furnace slag, Journal of the Society Chemical Industry Transactions & Communication, London ,59:191-202.

[25] GluchovskijV.D., Gruntosilikaty, Gosstrojizdat Kiev 1959, Patent USSR 245 627 (1967), Patent USSR 449894 (Patent appl. 1958, filled 1974).

[26] Frantisek Skvara, 2007, Alkali Activated Materials Or Geopolymers , Ceramics − Silikáty 51: 173-177.

[27] Zhang , Z H., Zhu, H J., Zhou, C H., Wang, H. 2016. Geopolymer from kaolin in China: An overview, Applied Clay Science 119: 31–41

[28] Yang, N., 1996. Physical chemistry basis for the formation of alkaline cementitious material. Part 2. J. Chin. Ceram. Soc. 24: 459–465.

[29] Yang, N., 1996. Physical chemistry basis for the formation of alkaline cementitious material. Part 1. J. Chin. Ceram. Soc. 24: 202–215.

[30] Roy, D.M., 1999, Alkali-activated cements - Opportunities and challenges, Cement and Concrete Research 29: 249–254

[31] Shi,C., Krivinko,P.V., Roy, D.M. 2006.Alkali activated cements and concretes. Abingdon, UK, Taylor and Francis, 177-219.

[32] Duxson, P., Fernandez-Jimenez, A., Provis, J.L., Lukey, G.C., Palomo, A., van Deventer, J.S.J. 2007. Geopolymer technology: The current state of the art. Journal of Materials Science, 42: 291–293.

[33] Hardijito, D., Rangan, B V. 2005, Development and Properties of Low Calcium Fly Ash-Based Geopolymer Concrete, Research report-GCI, Faculty of engineering, curtin university of technology, perth, Australia.

[34] Pacheco-Torgal, F., Castro-Gomes, J., Jalali, S. 2008. Alkali-activated binders: a review. Part1&II,About materials and binders manufacture, Construction and Building Materials, 22:1305-1322

[35] Komnitsas, K., Zaharaki, D. 2007.Geopolymerisation: a review and prospects for the minerals industry, Minerals Engineering, 20: 1261–1277.

[36] Shi, A. Fernández-Jiménez, A. Palomo, 2011, New cements for the 21st century: the pursuit of an alternative to Portland cement, Cement and Concrete Research, 41: 750–763

[37] Bligh, R., and Glasby, T. 2013. Development of Geopolymer Precast Floor panels for the Global Change Institute at University of Queensland. Proceedings Concrete Institute of Australia Biennial Conference, Concrete – Understanding Concrete, Gold Coast, Australia.

[38] Buchwald, A.M., Ch. Kaps , M. Hohmann, 2003. Alkali-Activated Binders And Pozzolan Cement Binders – Compete Binder Reaction Or Two Sides Of The Same Story? In Proceeding of the 11th International conference on the chemistry ofcement,Durban,SouthAfrica.1238-1246.

[39] Habert G, d'Espinosede LacaillerieJB, Roussel JB. 2011. An environmental evaluation of geopolymer based concrete production: reviewing current research trends. J Clean Prod 19: 1229–1238.

[40] Malone P.G, Randall C and Kirkpatrick T,(1985),Potential applications of alkali activated alumino silicate binders in military operations.GL-85-15.Geotechnical laboratory Department of Army, Washington DC.

[41] Jannie S.J vanDeventer, John L.Provis, Peter Duxson, (2012), Technical and commercial progress in the adoption of Geopolymer Cement, Minerals Engineering,Vol.29,pp 89-104.

[42] A. Palomo, M.W. Grutzeck, M.T. Blanco, 1999. Alkali-activated fly ashes. A Cement for the future, Cement Concrete Res., 29: 1323–1329.

[43] Heath, A., Paine, K., Goodhew, S., Ramage, M. and Lawrence, M., 2013. The potential for using geopolymer concrete in the UK. Proceedings of the Institution of Civil Engineers: Construction Materials, 166:195-203.

[44] Balaguru P, 1998, Geopolymer for protective coating of transportation infrastructures, Final report, FHWA.

[45] EREZAllouche, Louisiana Tech. university, (2009) Geopolymer concrete in a greener construction technology rising from the ash application,science and sustainability of coal ash, 23-29.

[46] CSIRO 2008 'Geopolymers: building blocks of the future', www.csiro.au/science/ps19e.html, accessed 24 January 2012. Associated in Smith, M., Hargroves, K., Desha, C., & Stasinopoulos, P. (2009) 'Factor 5 in eco-cement: Zeobond Pty Ltd.', ECOS,Magazine, www.ecosmagazine.com/?paper=EC149p21, accessed 24 January 2012.Wagners, (2012).

[47] EFC: Earth Friendly Concrete, [online] Available at:http://www.wagnerscft.com.au/files/2613/4731/0397/Wagners-Earth-Friendly-Concrete.pdf [Accessed 3 December 2014]

[48] Gourley, J.T. and Johnson, G.B., (2005) "Developments in Geopolymer Precast Concrete", Proceedings of the International Workshop on Geopolymers and Geopolymer Concrete, Perth, Australia, http://www.claisse.info/Proceedings.htm.

[49] Andrews-Phaedonod F, 2012,Reducing carbon foot print through the VicRoads,concrete in Australia,Vol.40(1), pp40-48

[50] Tom Glasby1, John Day, Russell Genrich, and James Aldred(2015) EFC Geopolymer Concrete Aircraft Pavements at Brisbane West Well camp Airport, Concrete Conference, Melbourne Australia 2015

[51] Provis, John, van Deventer, Jannie (Eds.), 2014, Alkali activated material, state of art Report, RILEM TC- 224-AAM,ISBN 978-94-007-7671-5.FHWA,(2010) Geopolymerconcrete,CPTPTechBrief, FHWA-HIF-10014,Washington DC.

[52] Sanjay Kumar and Rakesh Kumar. (2015). Synergizing Red (mud) and grey(ASH) for greener production, Bauxite residue valorization and best practices, Leuven,Vol.5-7

[53] Radhakrinshna, Venugopal K, Saslatti Vinod and Venumadhav T, (2015). Study on geopolymer masonry as sustainable building material, Journal of environmental research and development, Vol. 9 (3A), pp 925-932.

[54] RajamaneN.P., M.C. Nataraja and R. Jeyalakshmi, 2014. Discussion on "Pozzolanic industrial waste based geopolymer concretes with low carbon footprint", The Indian Concrete Journal, 88: 8, August, Special Issue on Future Cements, pp 45-46

[55] KolliRamujee et al, 2015. Performance characteristics of Geopolymer concrete, Indian concrete institute Journal (ICI), 16: 30-36.

[56] Rajamane N. P., M C Nataraja, R. Jeyalakshmi and S Nithiyanantham, 2015, Greener durable concretes through geopolymerisation of blast furnace slag", Materials Research Express, 2-5

[57] Qaisar, S. H., Ahmad, M. A. 2014, Production, Consumption and Future Challenges of Coal in India, International Journal of Current Engineering and Technology, 3437-3440.

[58] Ministry of Coal Source: http://coal.nic.in/content/coal-reserves., www.iflyash.com, www.ntpc.co.in, www.cfarm.org. http://www.cbrienvis.nic.in/flyashscenario., Fly ash utilizationunit.DST-GOI

[59] Bhattacharjee U, KandpalTC. 2002. Potential of fly utilization in India. Energy, 27:151–66.

[60] Ahmaruzaman M. 2010. A review on the utilization of flyashProgress in energy and combustion science", 36: 327-363.

[61] Haque, M.E. 2013. Indian fly-ash: production and consumption scenario. International Journal of Waste Resources. (IJWR), 3(1), 22-25.

[62] The Indian Steel Industry 2015, Key Reforms for a Brighter Future, A report by National council of applied research infor@ncaer.orgwww.ncaer.org.

[63] Reports by India brand equity foundation on realestate,cementhttps://www.ibef.org/download/ steel-June-2017, www.ibef.org. DIPP, TechSci Research

[64] Glukhovsky V.D, Krivenko P.V 1988., Manufacture of concretes and structures from slag alkaline binders, Budivelnyk Publish, Kiev, Ukrain.

[65] Brodho O A 1999, Experience of exploitation of alkaline cements concrete. Ed. Krivenko P., Proceedings of the second international conference on Alkaline Cements and Concrete. 657-684.

[66] Davidovits , J, and Sawyer, J.L. 1985 US patent 4, 509,985., office U.S.P (ed) Pyrament Inc USA.

[67] Malone P G, Randall C J, Kirkpartick T ,1985. Potential applications of alkali activated aluminosilicate binders in military operations. Geotechnical Laboratory Department of Army, GL 85-15.

[68] Palomo A, Fernandez-Jimnenz a., Lopex-homrados C and Lleyda J.L 2007. Railway sleepers made of alkali activated fly ash concrete Rev . Ing. Construction 22, vol 2 PP 75-80. http://dx.doi .org/10.4067/S0718-50732007000200001.

[69] Xu.H., Provis JL., van Deventer J.S.J and Krivnko p V .2008. Characterisation of slag concretes ACI Mater J vol 105 (2) pp 131-139.

[70] Palomo A, Krivenko P Garcia-Lodeiro I, Kavelerova E., Malteseva O., Fernandez-Jimenez A., 2014. A review on alkaline activation: New analytical perspectives, Materials De Construction, Vol.64, pp.1-25, http://dx.doi.org/10.3989/mc.2014.00314.

[71] J G.SANJAYAN.2017 Material technology research to structural design of geopolymer concrete. Mechanics of structures and materials XXIV. Proceedings of the 24th Australian conference,December2016.edited by HangHao, Chunwei Zhang., CRC press, Taylor & Francis group) pp 31-40.

[72] The Ministry of Construction of Enterprises of the USSR. of Heavy Industry. Standard-Slag alkaline binders, Technical specifications OST 67-11-84., 1984, Moscow.

[73] DSTU B V 2.7-181 (2009) Alkaline cement specifications National standard of Ukraine, Kiev.

[74] ASTM International Standard Performance Specification of Hydraulic cement, West Conshokocken, 2010, (ASTM C c1157/C1157M).

[75] British Standard Specification 2016. Alkali Activateed Cementitious materials and concrete-Specifications: PAS 8820-58.

[76] Berndt ,M., Sanjayan J., Foster S.,Castel A.,Rajeev P.,Heidrich C 2015. Progress towards handbook for geopolymer concrete .,Concrete 2015.Proceedings of the Biennial Conference of the concrete Institute of Australia in conjunction with 69th RILEM week 30th August to 2nd September, 2015,Melbourne, Australia.

[77] Andrews –Phaedonos F 2013, Vicroads guidelines. Sections 703 –General concrete paving., Section 701-underground storm water drains., Section 705-Drainage pits.,Section 711-wire rope safety barrier

Table 2. *Barriers &Solutions to Faster Geopolymer Technology Uptake by Stakeholders*

S. No	Parameters	Barrier	Solution
01	Supply chain geopolymer raw materials.	(i) Economic way of utilization in geopolymer is limited. (ii)Data on actual generation of industrial wastes Fly ash/slag and its consumption across different parts of India is not available. (ii)Specification, life time, method of storage and bulk handling of Alkali solution in Geopolymer production is un available.General specification of chemicals is not applicable for quality production.	Devise methods for collection and integration of information top-bottom and bottom-up on supply chain of materials and feasibility for commercial production to create market size. Technical manual preparation for quality control.
02	Techno-knowledge.	User related factors such as systematic or/predictive information regarding methodologies or heuristic procedures by which activators can be optimally matched to different raw materials and their proportions are proprietary or customized.	Design program to increase the production of geopolymer / products. Implementation through pilot level projects. Availability of Material data sheet, construction technologies for adaptation by stakeholders to create market
	Code of practice for utilization of industrial wastes in the production of geopolymers	Absence of performance based certification system to geopolymer products.	National certification system for assessing the performance of geopolymers and their products to provide performance based standards instead of prescriptive ones.
03	Cost economics	High cost and Competitiveness against cement and fly ash based products. Lack of capital investment required for covering Incremental cost in reaction generating liquid	Developing attractive finance models to provide finance to developers for investing in production of geopolymers. Attractive financing solutions for home buyers/developers investing in green homes. Publicize the fact that geopolymer products assist for green rating for building
04	Capacity building	Lack of subject experts, Architects/ services consultants/ building contractors	Organisation of Capacity building program at different level for propagation with the help of Local and state level government officials for an effective uptake by stakeholders.
05	Awareness	Lack of information on benefits and co-benefits of geopolymers	National and sub-national extensive media campaign; advertising , pilot projects executed by various agencies and building centers across the country