INDIAN CONCRETE INSTITUTE
Bengaluru Centre

In association with

DAYANANDA SAGAR COLLEGE OF ENGINEERING
Bengaluru

Organises

1-Day National Seminar on

Geopolymer Concrete Applications: Challenges and Opportunities

(Smart Techniques and Solutions for Ecofriendly Sustainable Constructions)

On 18th February 2020, Tuesday

Venue: Premachandra Sagar Auditorium, DSCE, Kumaraswamy layout Bengaluru – 560 078

INTRODUCTION: GEOPOLYMER CONCRETE

In this drastically developing world it becomes very important for us as civil engineers to focus both on the global development and also its impact on the environment. This kind of approach leads to many innovations and researches which helps in conserving the environment without compromising on the developments. One such innovative technology is the geopolymer concrete.

Geopolymer concrete is an eco-friendly technology which makes use of the waste by products (fly ash, ground granulated blast furnace slag, etc.) from the various other industries in the preparation of the concrete instead of the ordinary Portland cement (OPC). The evidences from various researches show that using of OPC in the preparation of concrete leads to almost 5-8% of the manmade global carbon-di-oxide emissions. By using materials like the fly ash and GGBS for the preparation of the concrete almost reduces the carbon-di-oxide emission by 90% when compared to the usage of OPC in concrete.

In line with this continuing endeavour, ICI-BENC is organising a 1-Day Seminar entitled **"Geopolymer Concrete Applications: Challenges and Opportunities"** on **18th February 2020, Tuesday, at Premachandra Sagar Auditorium, Dayananda Sagar College of Engineering, Bengaluru.** Get to know from the experts and hands-on professionals will speak on vital aspects.

Please register early to book your seats in advance, as registration is limited. Limited Sponsorship slots are also available. Please get in touch with ICI-Bengaluru Centre office. For more information and for registration (contact details mentioned overleaf).
We look forward to meet you at this Seminar for a wonderful interaction of professionals, knowledge-updation and skill-enhancement.

TO REGISTER AND FOR MORE DETAILS, PLEASE CONTACT:

Dr. L R Manjunatha
Chairman, 9480682100

Dr. R L Ramesh
Secretary, 98456 57560

Dr. C P S Prakash
Principal, DSCE, Bengaluru

Dr. H K Ramaraju
Hod, Civil Dept, DSCE, Bengaluru

Indian Concrete Institute – Bengaluru Centre, Karnataka
No.2, UVCE Alumni Association Building, K. R. Circle, Bengaluru – 560001. Phone: 080-22224803 **Md. Pasha** : +91 89516 07887
Email: icikbc@gmail.com, secretary.icibc@gmail.com Website: http://www.icikbc.org, http://www.indianconcreteinstitute.org

1-Day National Seminar on

"Geopolymer Concrete Applications: Challenges and Opportunities"

On 18th February 2020, Tuesday

Venue: Premachandra Sagar Auditorium, DSCE, Kumaraswamy layout Bengaluru – 560 078

Session - 1

Keynote address & Presentation on –
A comparison between concretes made using Geopolymer and Portland cement as binders

Dr. Rajamane N P
Head - CACR
SRM Institute of Science and Technology,
Chennai.

Session - 2

Presentation on –
Geopolymer: An Alternative Binder

Dr. R V Ranganath
Professor, Dept of Civil Engineering,
BMS College of Engineering, Bengaluru.

Session - 3

Presentation on –
Geopolymer composites to cater the needs of costal area producing the same by using marine water

Dr. T. Venu Madhav
PRINCIPAL
Audisankara Institute of technology
Gudur (A.P), India.

Session - 4

Presentation on –
Development and applications of Geopolymer masonry

Dr. Radhakrishna
Professor & Head, Dept of Civil Engineering,
R.V. College of Engineering, Bengaluru

Session - 4

Presentation on –
Applications of Geopolymer Concrete

Prof. SK Singh
Senior Principal Scientist & Professor, AcSIR,
CSIR-Central Building Research Institute,
Roorkee-India

Please Note: Schedule is subject to modifications depending on contingencies that may arise.

DELEGATE FEE:

Members of ICI, ACCE, INSTRUCT	**- Rs. 1,500**
Non-member	**- Rs. 2,000**
ICI Student Member	**- Rs. 750**
Non-Student Member / Research Scholars	**- Rs. 1,000**

For Payment through online banking, please note the following details:

Electronic Transfer: RTGS / NEFT Details :

Account Name : Indian Concrete Institute – Karnataka, Bangalore Centre
Account No. : 04121010000530
Account Type : Current Account
Name of Bank : Syndicate Bank
IFSC Code : SYNB0000412
Branch Name & Address : **J.C. Road Branch,** Jasmine Mansion, J C Road, Bengaluru – 560 002 Karnataka.
Pan No : AAATI0256J / GSTN No : 29AAATI0256J1ZM

SPONSORSHIP & MARKETING COLLATERALS:

Gold Sponsor: Rs.50,000/- *(Includes free admission to 5 delegates + insert of Three technical literatures in Delegate Kit). Presentation slot of 10 minutes will be allowed + One standee space & Logo display at backdrop.*

Silver Sponsor: Rs.25,000/- *(Includes free admission to 3 delegates + insert of Two technical literatures in Delegate Kit). One standee space & Logo display at backdrop.*

Supporting Orgn.: Rs.15,000/- *(includes free admission to 2 delegate + insert of One technical literature in Delegate Kit) & Logo display at backdrop.*

Rs.10,000/- *Insertion of Two-Marketing collaterals in Delegate Kit:*

Above payments are excluding GST 18%

Please email receipt / reference number clearly mentioning your name and date of remittance, to: icikbc@gmail.com, so as to receive a confirmation of your registration from ICI office.

GET TO KNOW MORE FROM EXPERTS & PRACTISING PROFESSIONALS IN THE INDUSTRY. ENROLL TODAY!

Limited Seats. Please registration early as registration is on 'First-come-first-served' basis.

****Session durations subject to change. Decision of ICI-BC shall be final and binding on matters of interpretation w.r.t this Seminar.***

“Geopolymer Concrete Applications: Challenges and Opportunities”

About the Seminar

Polymer is a **substance which has a molecular structure built up chiefly or completely from a large number of similar units bonded together**. Alternative Eco-friendly materials and promoting for the sustainable management of resources. Department of Civil Engineering organizes national seminar every year. The primary objective of this seminar is to upgrade the knowledge of the participants with regard to latest technological developments in all the respects of research fields. Main concern in the concrete sector is sustainability, which can be brought out by the use of eco-friendly materials and other polymers.

Geopolymer concrete is an eco-friendly technology which makes use of the waste by products (fly ash, ground granulated blast furnace slag, etc.) from the various other industries in the preparation of the concrete instead of the ordinary Portland cement (OPC). The evidences from various researches show that using of OPC in the preparation of concrete leads to almost 5-8% of the manmade global carbon-dioxide emissions. By using materials like the fly ash and GGBS for the preparation of the concrete almost reduces the carbon-di-oxide emission by 90% whencompared to the usage of OPC in concrete. Major points to be discussed during national seminar will be effect of use of polymers on the concrete material and its characteristics mix design. The theme brings together panel of experts to prepare a blue print for management of eco- friendly materials.

Dayananda Sagar College of Engineering

The college was started in the year 1979 with four branches including Civil Engineering. It was founded by Sri. R. Dayananda Sagar under the aegis of Mahatma Gandhi Vidyapeeta Trust. Dayananda Sagar Institutions have extended its branches with campuses namely Dayananda Sagar Academy of Technology and Management (DSATM) and Dayananda Sagar University (DSU). Today DSCE is offering 15 Under Graduate Programs, 13 Post Graduate Programs and 20 Research Centers in different branches of Engineering. It is an Autonomous Institute affiliated to Visvesvaraya Technological University (VTU), approved by AICTE & ISO 9001:2015. The institution is accredited by NBA, National Assessment & Accreditation Council (NAAC) with “A” grade and approved by UGC. The department of Civil Engineering has been recognized as R&D Centre, undertaking Research work leadingtoMSc Engineering and Ph.D. The department is having funded projects from AICTE, ISRO, VTU, MOES, MOS etc and consultancy projects in Rural Development, Environmental and Structural Engineering.

Indian Concrete Institute – Bengaluru Centre, Karnataka

CI - Bangalore Centre, is successfully being run by an able adoptive and progressive managing committee since then. It is one of the active centres which conduct several programs every year. The membership is growing progressively day by day.

Objectives

- Promote growth of concrete construction and its sub-specialization.
- To disseminate information and train personnel by organizing seminars / conferences / workshops.
- Training programs for Fellow Members / Students and Corporate.
- Collaborate with National / International Agencies.
- Identify R & D problems of practical relevance.
- Arrange National and International Workshops, Conferences, Seminars, Deminars & Exhibitions
- Arrange Annual Lecture series on selected topics of relevance to Concrete Constructions
- To identify and recognize outstanding construction and outstanding performers in the field of Concrete Technology / Construction.

Expert Speakers

The seminar has focused its attention in the form of technical session such as concrete and their mix design concepts, use of polyers in concrete construction, we hope the present seminar would serve as a link between technology, policy, practice and decision making in the quest for advanced solutions for sustainable development. Thus a panel of experts from government, public sector and private sector invited to deliver the lecture on “Geopolymer Concrete Applications: Challenges and opportunities” A smart Techniques and solutions for ecofriendly sustainable construction.

ONE DAY NATIONAL SEMINAR ON

"Geopolymer Concrete Applications: Challenges and Opportunities"

(Smart Techniques and Solutions for Eco-friendly Sustainable Constructions)

Venue: Premachandra Sagar Auditorium, Dayananda Sagar College of Engineering, Kumaraswamy layout Bengaluru – 560 078

Program schedule: on 18th February 2020, Tuesday

Program schedule

SI. No	Duration	Timings	Details of program
1	60 min	8.30 am – 9.30 am	**Registration**
2	10 min	9.30 am – 9.40 am	Welcome address by **Dr. L R Manjunatha**, Chairman ICI(BENC)
3	20 min	9.40 am – 10.00 am	**Chief Guest: Er Srinivasa Reddy,** M/s. DesignTree Service Consultants Pvt Ltd, Bengaluru. **Guest of Honour:** **Er. S Suresh,** Vice President (south) ICI Mr. R Radhakrishnan, Secretary General ICI **Dr. C P S Prakash,** Principal, DSCE., & **Dr. H K Ramaraju,** Prof & Head, Dept. of Civil Engg, DSCE. **Followed by Lighting of Lamp by Dignitaries**
4	75 min	10.00 am – 11.15 am	**Session 1:** Keynote address on – "A comparison between concretes made using Geopolymer and Portland cement as binders" **By Dr. Rajamane N P,** Head – CACR, SRM Institute of Science and Technology, Chennai.
5	20 min	11.15 am – 11.35 am	**Sponsor presentation slot – 1** **M/s. KUTTUVA SILICATES P.LTD, Chennai**
6	15 min	11.35 am – 11.50 am	**Tea/coffee - Break**
7	60 min	11.50 am – 12.50 pm	**Session 2:** Presentation on – " Geopolymer: An Alternative Binder" **By Dr. R V Ranganath,** Professor, Dept of Civil Engineering, BMS College of Engineering, Bengaluru
8	40 min	12.50 pm – 01.30 pm	**Lunch Break**

9	60 min	01.30 pm – 02.30 pm	**Session – 3:** Presentation on – "Geopolymer composites to cater the needs of costal area producing the same by using marine water" **By Dr. T. Venu Madhav,** Principal, Audisankara Institute of Technology, Gudur (A.P)
10	20 min	02.30 pm – 02.50 pm	**Sponsor presentation slot – 2** **M/s. Concrete Additives and Chemicals Pvt Ltd** "Corrosion Protection of RC structure using CAC CORROBIT OCI" from Carbonation and Chloride Contamination" **by Mr. Sriram Thiagarajan -** R&D head /CAC
11	60 min	02.50 pm – 03.50 pm	**Session – 4**: Presentation on – "Development and applications of Geopolymer masonry" **By Dr. Radhakrishna,** Professor & Head, Dept of Civil Engineering, R.V. College of Engineering, Bengaluru
12	10 min	03.50 pm – 04.10 pm	**Tea/coffee - Break**
13	20 min	04.10 pm – 04.30 pm	**Sponsor presentation slot – 3 M/s.**
14	60 min	04.30pm – 05.30 pm	**Session – 5:** Presentation on – "Applications of Geopolymer Concrete" **By Prof. SK Singh,** Senior Principal Scientist & Professor, AcSIR, CSIR-Central Building Research Institute, Roorkee-India
15	10 min	05.30pm – 05.40 pm	Feedback from participants
16	05 min	05.40pm – 05.45 pm	Vote of thanks by **Dr. R L Ramesh**, Secretary ICI (BC)

Technical Note on

Use of Factory Made Reaction Generating Liquid (RGL - SRGPJ1) to Produce Geopolymer Concretes

Dr. Rajamane N P,

1.0 INTRODUCTION

Geopolymer binders, formed by alkaline activation of aluminosilicate precursors, are attracting interest as "green" cements because through the use of industrial wastes such as geothermal silicas, fly ashes and mineralogical slags as source materials. There is the possibility to achieve a significantly lower CO_2 emission per tonne of concrete in comparison with OPC. With increasing production volumes, they can become cost-competitive with Portland cement. They have found utilisation in major infrastructure projects internationally, initially in the former Soviet Union and in China, and now increasingly in Australia and elsewhere internationally since the political and financial incentives for CO_2 emission reductions are growing.

There are many aspects in the geopolymer synthesis chemistry and geopolymers are considered as **High alkali (K/Na-Ca –Poly –Sialate-Siloxo)** binder with network of Si, Al and charge balancing ions. For a chemical designation, geopolymers based on silico-aluminates, the term 'poly (Sialate)' [Sialate is abbreviation of silicon-oxo-aluminate; Sialate= Si – Al - ate] was suggested. The Sialate network consists of SiO_4 and AlO_4^- tetrahedra linked alternately by sharing of all the oxygens. Positive ions , {Na^+, K^+, Li^+, Ca^{++}, Ba^{++}, $NH4^{+,}$ $H3O^+$ }must be present in the molecular framework cavities to balance the negative charge of Al^{+3} in IV coordination. Some related structural units are presented in Fig 1.0 and Fig 2.0. The linkages shown in Fig. 2 become feasible due to presence of alkali metal ions such as Sodium or Potassium (for the purpose of Charge balancing in the Molecular chain) when the 4-coordinated Silicon is substituted by 4-coordinated Aluminium (Fig 2).

Geopolymers are a broad class of materials produced by the dissolution and poly condensation of alumino silicate in highly alkaline medium. This class of material is also commonly referred to in the literature as "Inorganic polymers" or 'alkali activated cements'. They can be produced from a wide range of source materials which in turn gives them a wide range of physical properties. This allows geopolymers to exhibit properties that can make them suitable for applications ranging from conventional binders to high end applications including the fields of Energy, Space, and Nuclear fields. In particular, the Geopolymers (GPs) can function as binder similar to Portland cement.

Geopolymer Synthesis: The alumino-silicate polymers are made from powdery Geopolymeric Source Materials (GSMs), whose chemical oxide composition consists of Al_2O_3 and $SiO_{2,}$ the most common examples being: Fly Ash (FA) and Ground Granulated Blast Furnace Slag (GGBS). For this powdery mix, a liquid known as Reaction General Liquid (RGL) – SRGPJ1 is added for initiating the binding action creating reaction called geopolymerisation. The RGL basically raises the Si/Al ratio in the aqueous solution to enable faster condensation reactions (of the geopolymerisation) to produce geopolymers of desirable characteristics.

At present, in the present case, an optimised RGL formulation is made available for the personnel working in the field of the Geopolymer Technology, to generate geopolymerisation reactions at ambient temperature conditions for the GSMs made from mainly several combinations of FA and GGBS for varieties of applications. The composition of RGL is selected in such a way as to generate the geopolymerisation reactions at ambient temperature conditions and to maintain proper ratios of Si/Al Na/Al and Na/Si needed to form the geopolymeric network structure. The formation and stability of the binder using the SRGPJ1 with varied proportions of FA and GGBS have been confirmed by Standard test methods/protocols by SRM team. Various samples of SRGPJ1, the role of ions/species present in it and their participation during the reactions are well studied and the stable geopolymer binders with required structural features were found to get formed.

Patenting and IPR related processes are under way. During the preparation of RGL, a very careful relative proportioning of alkali hydroxide and alkali silicate solutions becomes essential. In the present case of factory made RGL, a few special chemical additives were identified and added for obtaining the improved properties of geopolymer mixes at fresh and hardened stages.

Main features of Geopolymer Concrete (GPC), as different from Conventional Concrete (CC) are:

(i) 100 % replacement of Portland cement by powdery Geopolymer Source Materials

(ii) 100% usage of RGL (basically, an aqueous solution) in preparation of fresh concrete mixes, in place of mixing water in CC.

However, mixing equipment and many operations/procedures of CCs are adoptable for GPCs (with minimum modifications).

Thus, generally, Geopolymer Concretes (GPCs) have zero OPC with no direct mixing water.

2.0 PROPERTIES OF RGL (REACTION GENERATION LIQUID: -SRGPJ1

(i) The density of the RGL is in the range of 1.20 +/- 0.05 kg/lit.

(ii) Viscosity of the liquid is in the range of 25-50 Centipoises depending upon the ambient temperature and humidity conditions.

(iii) The storage life of the RGL is generally 30 days when stored in airtight containers, inside the building without direct exposure to heat, sunlight and rain, etc. It may be noted here that in one of the field trials, it was found that the RGL was working very well for more than 60 days also after transporting to the field which was at a distance of more than 1000 km, when rational storage conditions were made available .

(iv) The present RGL is formulated to suite GSMs containing Fly Ash and GGBS where the GGBS content is about 50% to 80% (i.e., the balance Fly Ash being 20% to 50%), for concrete strengths in the range of 30-50 MPa; higher GGBS contents give higher levels of concrete strengths in faster way

(v) When the Fly Ash content of GSM is 75% and more, the strength levels obtained in the geopolymer concretes could be in the range of 5-30 MPa. These strengths are mostly useful for masonry applications such as building blocks, etc.

(vi) The strengths mentioned above are only indicative in nature and the actual values depend upon:

- properties of ingredients of GSM,
- mix proportions,
- RGL content in the mix,
- ambient temperature and humidity conditions,
- curing regimes adopted, etc.

(vii) The RGL solution mentioned here could contain some minor amounts of chemical additives which aid in enhancing the performances of the geopolymer mixes, especially during fresh concrete stages only.

3.0 GENERAL GUIDELINES ON USE OF RGL –SRGPJ1

(i) The composition of RGL - **SRGPJ1** is suitable for achieving strength levels in GPCs similar or higher levels, compared to many conventional concretes, with the faster rates of strength development and also to reaching higher levels of durability in many geopolymer formulations and field conditions. The GPCs have almost no alkali-aggregate reactions.

(ii) It is to be noted that the actual strength and rate of development of strength achieved are dependent on various parameters such as mix propositions, liquid / solid ratio, chemical and physical properties of Fly Ash and GGBS, ambient temperature and humidity conditions, mixing equipment, curing regime and duration, etc.

(viii) The users of RGL can modify their existing concrete/mortar mixes (with satisfactory workability/mouldability) based on following guidelines in general:

a) For workability

(i) The 'Q' kg of mixing water can be replaced by '1.18*Q' kg of RGL (Table 1). However, if the mix can be made with quantity lesser than this, it should be adopted. It is always preferable to use RGL as much less as possible.

(ii) The powdery portion of CC i.e., Portland cement powder should be replaced powdery GSM in equal absolute volume basis. Towards, a tentative for every 100 kg of OPC, the quantity of FA and GGBA required is given in Table 2.

(iii) The inert filler portion in the form of coarse and fine aggregates, of the CC can remain same essentially. However, minor adjustments in actual quantities may be required in some cases.

b) For strength
Trials on GPC mixes should be made with different GSMs consisting of various combinations of FA and GGBS and the combination meeting the requirement of concrete strength can be selected.

c) Admixtures
In general, admixtures of CC (such as superplasticiser) should be avoided since they are not developed for GPC mixes and their presence may affect the strength and its development rate.

(iii) The present RGL is generally formulated for making geopolymer concrete mixes suitable for demoulding operations within 24 hours of casting. However, hot air and / or steam curing can also be adopted to get accelerated strength gain

(iv) It is recommended that immediately after casting, the moulds containing fresh geopolymer concrete mixes should be covered with wet gunny clothes so that there is no loss of liquid (RGL) from the mix, i.e., drying is avoided.

(v) When the RGL is used for production of building blocks/pavers, it is necessary to keep the freshly moulded blocks under the shade within the building and without any direct exposure to sun, wind, high temperatures, etc. At least up to 24 hours (preferably up to 48 hrs) after moulding, the blocks must be covered with wet gunny clothes or stored in a curing area/room where humidity is more than 95%

(vi) The characteristic tests should be carried out on RGL at the users-end regularly and they could be specific to the requirement of the any particular applications

(vii) The strength levels for Geopolymer Concretes mentioned herein are only indicative in nature, but, strengths much higher the indicated here is possible, if suitable mix ingredients and formulations are identified by separate study and used

(viii) In geopolymer technology, it is preferable to use weigh-batching only and hence, volume batching must be avoided

4.0 PRECAUTIONARY MEASURES IN THE USAGE OF RGL

(i) The RGL stored in the drums and other storage vessels should not be exposed directly, at any time, to atmosphere since the RGL is prone to carbonation reaction due to CO_2 available in the atmosphere.

(ii) It is generally recommended to adopt suitable safety measures and tools such as hand gloves, safety glasses, gum boots, etc, which are usually adopted for Portland cement (PC) based activities.

(iii) RGL is not edible and they should be kept away from children. Touching and mixing with bare hands must not be done.

(iv) Direct contact with eyes should be avoided.

(v) Any addition of extra water without prior tests should not be permitted

(vi) General precautionary and safety measures as applicable to handling of alkali hydroxide and silicate solutions must be adopted here also.

5.0 FIELD TRIALS ON RGL –SRGPJ1

5.1 Precast Products at CASHUTEC, Raichur, Karnataka

More than 5 tonnes of RGL was procured from KSPL, Madurai and many GPC mixes were prepared to cast many products using the ingredients available (such as sand, coarse aggregates, quarry dust, fly ash, GGBS, etc) and the mixing and casting facilities available (**Photos 1, Table 3**). A National Geopolymer Technology Demo Centre was inaugurated on 30 Jan 2019 at Raichur where more than 30 products are displayed.

5.2 GPC Road at Raigad, Chhattisgarh

More than 80 tonnes of RGL was supplied by KSPL, Madurai and after many trials, suitable GPC mixes were developed to lay a demo stretch of fly ash-GGBS Based Geopolymer Concrete road using conventional mixing, transportation, road laying equipments (**Photos 2**). The field engineer having more than 2 decades of experience in road construction expressed his satisfaction at the nature of GPC mixes produced. There are plans to adopt these mixes for relaying several kilometres and efforts are being to install the RGL production facility in Chhattisgarh itself.

5.3 GPC Building Blocks at SRMIST

The RGL of KSPL, Madurai was used in production of several GPC mixes to cast several types of pavers, building blocks, etc with the help of regular vibro-compaction electric operated block production machine available with private agency nearby to SRM Campus. (**Photos 3**).

5.4 GPC Pavers at Commercial Concrete Block Production Plant in Chennai

The RGL was used in a running concrete block production factory in suburbs of Chennai to produce pavers of several shapes and sizes which were either similar or often superior properties to Portland cement concrete based products. The costs of production of these high strength GPC paver/building blocks were found to be lower than those of conventional products (**Photos 4**).

5.5 Egg Laying Type Machine for GPC Block Production in Chennai

The on-site production of GPC blocks with the RGL was demonstrated using an Egg Laying Type of Block Making Machine. Traditional mixer machine, transport, and machine etc were found to be useful to produce blocks with strengths in the range of 5 to 15 MPa which is enough for any masonry application in general (**Photos 5**).

6.0 ADVANTAGES OF FACTORY MADE RGL

[1] Civil Engineers on field would find it difficult to understand, prepare and measure the molar concentration of Sodium Hydroxide solution. Another component of Alkaline Activator Solution described in the literature is commercially available factory made Sodium Silicate Solution (SSS). Actually, the term 'Sodium Silicate' does not represent the unique single chemical, but, it can be considered as a generic name for the chemical with oxide compositions of Na_2O and SiO_2 in variety of proportions. When such a silicate solid is dissolved in water, the Sodium Silicate Solution (SSS) is formed. This solution is available commercially in many forms with varying contents of Na_2O and SiO_2 and their concentrations; each of them could act differently in Geopolymer reactions and hence selection and systematic testing of Sodium Silicate Solution is essential for civil engineering applications so that the desirable Geopolymer reactions occur.

[2] By using factory made RGL, the GP reactions do occur in GSMs to produce GPC mixes of many varieties with different properties, but, without any necessity for field people to understand the exact chemical composition of the RGL and the details of chemical reactions involved.

[3] The RGL acts as a liquid component of the concrete mixes in the way of similar to that of the conventional concretes, especially in fresh concrete stages. Therefore, by varying the content of RGL in the Geopolymer mixes, their desired level of workability in GPC mixes can be achieved. In this connection, the Lyse's rule explaining the effect of water content on the workability of conventional concrete mixes, can be applied to GPC mixes also.

According to Lyse's rule, the volume of the liquid in the concrete mix largely determines the workability of the concrete mix for a given maximum size of aggregate. Therefore, in designing GPC mix, initial RGL content of the GPC mix can be considered as equivalent to water content on volume basis. However, because of the higher density of RGL compared to water, the RGL content by weight is generally numerically more than that of water content of the corresponding conventional concrete mix.

After fixing the RGL content in the GPC mixes as discussed above, it is possible to achieve various strength levels in GPC mixes by different combinations of Fly Ash and

GGBS. Here again, by developing GPC mix, the absolute volume of cement particles can be considered and replaced by the fine particles of Fly Ash and GGBS on equal absolute volume basis. Towards this, Table 2 of this technical note can be as the reference.

[4] Using the guidelines mentioned in this note for determining the RGL, Fly Ash & GGBS contents, GPC mix design will be largely similar in general to that of conventional concrete.

[5] Since the factory produced RGL commonly produces sufficient strength within 24 hours of mixing and casting for most of the combination of Fly Ash & GGBS, the demoulding time is not much different from that of conventional concrete.

[6] Since the strength gain in GPC mixes occur by Geopolymerisation reaction, there is no necessity for creating external conditions thereby the GPC get cured by just exposure to ambient room temperature conditions. This simplifies the construction practises in the field since the much needed external curing to needs of the conventional concrete is completed eliminated in case of the GPC mixes.

[7] As a strength gain in mechanism in GPC is by polymerisation, not by hydration reactions, the rates of strength development of the GPC are generally more than the conventional concretes. This is advantageous in the field conditions, especially in precast situations.

[8] In the absence of the factory made RGL, the published literature shows that the field engineers have to adopt the cumbersome process of preparing alkali hydroxide solutions of required molarity and mixing with commercially available alkali silicate solutions which need very careful selection. This step is eliminated when the factory RGL is used thereby simplifying the processing of GPC mixes in civil engineering field applications.

[9] It is noted here that the preparation of NaOH solution involves generation of large quantity of heat. This stage is taken care now in the plant producing RGL. Hence, elaborate special requirements of equipment and procedure to produce NaOH in very large quantities is completely eliminated in the construction field. This is a major factor for simplifying the preparation of GPC mixes on the site.

[10] Though the factory produced RGL is basically a Sodium Silicate Solution the formulation of this RGL is made suitable for producing GPC containing Fly Ash and GGBS. This eliminates the need for Portland cement to produce concrete mixes in the construction field.

[11] The production of RGL in the factory ensures consistent Geopolymer reactions in the GPC mixes for any civil engineering applications.

[12] The geopolymerisation reactions are intrinsic in nature, without any need for external curing operations. This means, GPC with the factory produced RGL are of self curing in nature as just exposure of the demoulded GPC components to the ambient conditions is enough for strength development purposes.

[13] The water used for external curing of conventional concretes after demoulding is eliminated in the case of GPCs. This means the water requirement in construction field is reduced considerably, which is a highly welcomed features of GPC technology.

[14] The Embodied Energy and the Embodied CO_2 Emission contents of Portland cement are about 4 GJ / tonne and 0.7 to 0.9 tonne / tonne respectively. These are very high values and contribute mostly to the high carbon footprint of the conventional concretes. The GSMs such as Fly Ash and GGBS have almost negligible amount of Embodied Energy and Embodied CO_2 Emission, the carbon footprint of the GPC mix is much smaller than that of conventional concrete. The published literature indicated that there is a saving of more than 50% in respects of Embodied Energy and the Embodied CO_2 Emission contents.

[15] The basic source materials used to manufacture the present RGL are common chemicals and therefore, a sustainable long time production of RGL is possible.

7.0 CARBON FOOT PRINT OF GPC USING RGL:

The carbon foot print is measured by two parameters -

(1) Embodied Energy (EE)

(2) Embodied Carbon-di-oxide Emission (ECO_2e)

EE and ECO_2e contents of inert fillers system in the form of fine and coarse aggregates are not vary as compared to that Portland cement. The quantities of aggregates could remain almost same in both GPCs and CCs. The computation of carbon footprint of concretes is controlled mostly by the binder systems involved. Towards this, we can consider the carbon footprint of Portland cement alone in case of conventional cement concretes. This quantity can be compared with the carbon footprint of Geopolymer paste, which is sum of the carbon footprints GSM and RGL. Tentative typical calculations for this are given in Table 4, which shows that the GPCs will always have significantly lower carbon footprints. The typical calculation shown in Table 4 indicate that reductions in EE and ECO_2e contents of GP paste as compared to OPC paste are as much as 78% and 95% respectively. Thus, the GP composites must be preferred to OPC contacting composites from ecology point of view and this is a necessity in view of the Global Warming related damages faced by the mother Earth.

8.0 ECONOMICS OF GEOPOLYMER CONCRETES WITH FACTORY MADE RGL

[1] The cost of RGL determines in a major way, the economics of GPC. But, the actual cost of RGL on site depends actually on the the practical of application itself.

Case A:

The manufacturer of RGL when supplies it in small quantities, for trial studies/experiments, the cost will be towards the expenditures involved in packing the liquid in small containers (such as 25,50 litres) and transporting them to the places of trials mixing. This kind of procurement of RGL will be considerably more and hence, this price should not be used for calculating the economics of Geopolymer Concretes in a field situation.

Case B:

The manufacture can supply the RGL in 200 litre drums for actual field applications. Here, the cost of GPC could be supplied at much lesser cost than in Case A. (Case B cost can be about 40% less than the cost mentioned in Case A).

Case C:

In a large project, obtaining the RGL in 200 litre drums may be inconvenient, hence, there would be a necessity for establishing RGL production facility in the field itself. This type of RGL production would cost much less than that of the Case A and Case B. However significant capital investment may have to be made to fabricate the elaborate large storage tanks, piping and pumping systems etc.

In case of the very large size of the project, the initial capital expenditure can be justified. Then the RGL can be made available at very low cost and hence the GPCs could cost much less than that of conventional cement concretes, especially in case of higher grade of concretes.

[2] The above cases of A to C refer only to the intrinsic material related cost of the RGL at the site. However, since GPC does not use any Portland cement, EE and Embodied ECO_2e emission contents of the GPCs would be at least 30 to 40% lower than that of conventional cement concretes. Considering the ecological damages caused on use of high carbon footprint materials and some realistic economic / financial cost of saving the ecology damage is considered, then, the effective cost GPC could be, in most of cases, much lower. In Green Ratings of the construction, use of GPCs in place of CCs should be allotted more points.

It was observed in some particular situations that the material cost of the RGL at the place of manufacturing would be around Rs.10 per kg (based on June 2018 prices of the RGL ingredients). However, if the per kg cost of procurement of RGL in small quantities becomes as much as 25 to 50 Rupees per kilogram, this value should never be used in deciding the economics of using GPC technology in many applications. Since the quantity of RGL required could be, in any project site, easily in excess of hundreds of tons and the rational production, packing and transportation, storage systems etc could be planned suitably for logistic reasons also thereby the RGL cost becomes mostly ingredient materials' cost.

List of Abbreviations

GPs = Geopolymers

FA = Fly Ash

GGBS = Ground Granulated Blast Furnace Slag

RGL = Reaction General Liquid

GSMs = Geopolymer Source Materials

CC = Conventional concretes (

GPC = Geopolymer Concrete

Table 1` OPC and GSM equivalents (for equal absolute volumes)

(a) Weight equivalents (Details in Table 1(b) below

OPC	GSM, Wt		
	FA	GGBS	Total
kg	kg	kg	kg
100	60	10	70
100	54	19	73
100	47	28	75
100	40	37	77
100	34	47	81
100	27	56	83
100	20	65	85
100	14	74	88
100	7	83	90
100	0	93	93

(b) Nature of GSM wrt OPC

OPC	FA in GSM		GSM, Wt			GSM, Abs Vol.			OPC
			FA	GGBS	Total	FA	GGBS	Total	
kg	% Vol	% Wt	kg	kg	kg	litres	litres	litres	litres
100	90	87	60	10	70	28.6	3.2	31.7	31.7
100	80	74	54	19	73	25.4	6.3	31.7	31.7
100	70	63	47	28	75	22.2	9.5	31.7	31.7
100	60	52	40	37	77	19.0	12.7	31.7	31.7
100	50	42	34	47	81	15.9	15.9	31.7	31.7
100	40	33	27	56	83	12.7	19.0	31.7	31.7
100	30	24	20	65	85	9.5	22.2	31.7	31.7
100	20	15	14	74	88	6.3	25.4	31.7	31.7
100	10	7	7	83	90	3.2	28.6	31.7	31.7
100	0	0	0	93	93	0.0	31.7	31.7	31.7

GSM = Geopolymeric Source Material

Table 2 Water and RGL equivalents (for equal absolute volumes)

Water	kg	160	170	180	190	200
RGL	kg	189	201	212	224	236

RGL = Reaction Generating Liquid

Table 3 Precast Products at CASHUTEC, Raichur Karnataka
(These can be made both from fly ash concretes and geopolymer concretes)

- BRICK, Solid Block, Hollow Block, Inter Lock Block,
- Door Frame, Window Frame, Ventilator
- Hexagonal Paver, Flower Shape with Centre Hole Paver, Zig Zag Type Paver, I Shape Paver, Brick Type Paver, Flower Shape Paver, Grass Pavers,
- Anti Skid Tile, Anti Skid Tiles, Mosaic Tile,
- Fly Ash Ferro Cement Bench, Garden Bench (Nut Bolt System) , Garden Bench, Flower Pot, Tree Guard,
- Drain, Fencing Pole, Kerb Stone, Compound Wall, Rings, Covering Block,
- Kilometre Stone, Furlong Stone, Name Board, Guard Stone, Name Board,
- Lintel Cum Chejja Precast Bollard, Saucer Drain, Precast Drain Cover Slab,
- Precast Toilet, Paver Electric

Table 4 Carbon Footprints of Binder Pastes
(a) Basic data

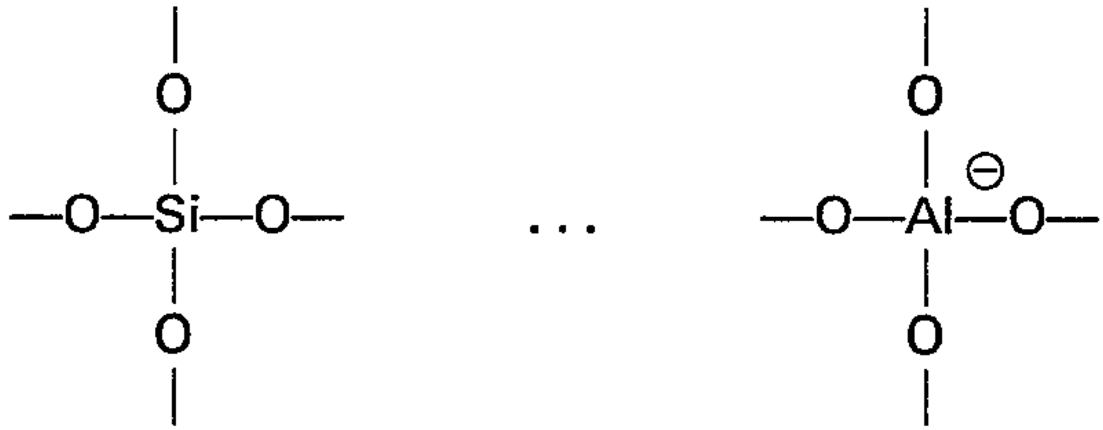
Paste Ingredients	Specific Gravity	Embodied Energy	ECO_2e	Cost	OPC paste, Proportions		GP paste, Proportions		
					Weight	Absolute Vol	GSM content	Absolute Vol	Weight
		MJ/kg	$kgCO_2e/kg$	Rs/kg	kg	litres	%	litres	kg
Fly ash	2.1	0.1	0.008	1			50	0.1587	0.33
GGBS	2.9	1.6	0.083	3			50	0.1587	0.46
GSM							100	0.3175	0.79
OPC	3.15	5.5	0.93	7	1	0.3175			
RGL	1.18	0.91	0.0051	11.5				0.4	0.47
Water	1	0.01	0.0008	0.01	0.4	0.4			
Liquid/Solid Ratio (L/S)					0.4	1.26		1.26	0.59

(b) Computations for Carbon footprint

Paste Ingredients	GP Paste		OPC Paste	
	Embodied Energy, EE, MJ/kg	Embodied CO_2e ECO2e kgCO2e/kg	Embodied Energy (EE) MJ/kg	ECO_2e kgCO2e/kg
Fly ash	**0.033**	**0.0026**		

GGBS	**0.736**	**0.0382**		
GSM	**0.769**	**0.0409**		
OPC			5.5	0.93
RGL	0.429	0.0024		
Water			0.004	0.00032
Total	1.199	0.0432	5.504	0.93

% Reduction between OPC and GP Pastes,
For EE, 100*(5.504-1.199)/5.504=78%, For ECO_2e, 100*(0.93-0.043)/0.93=95%



4 coordinated Silicon **4 coordinated Aluminum**

[Silicon element’s 4 valencies are satisfied satisfied.

[Aluminium element’has 3 valencies, but, its are 4 coordination to oxygen makes the $AlO4^-$

Fig 1 Basic units of Geopolymer

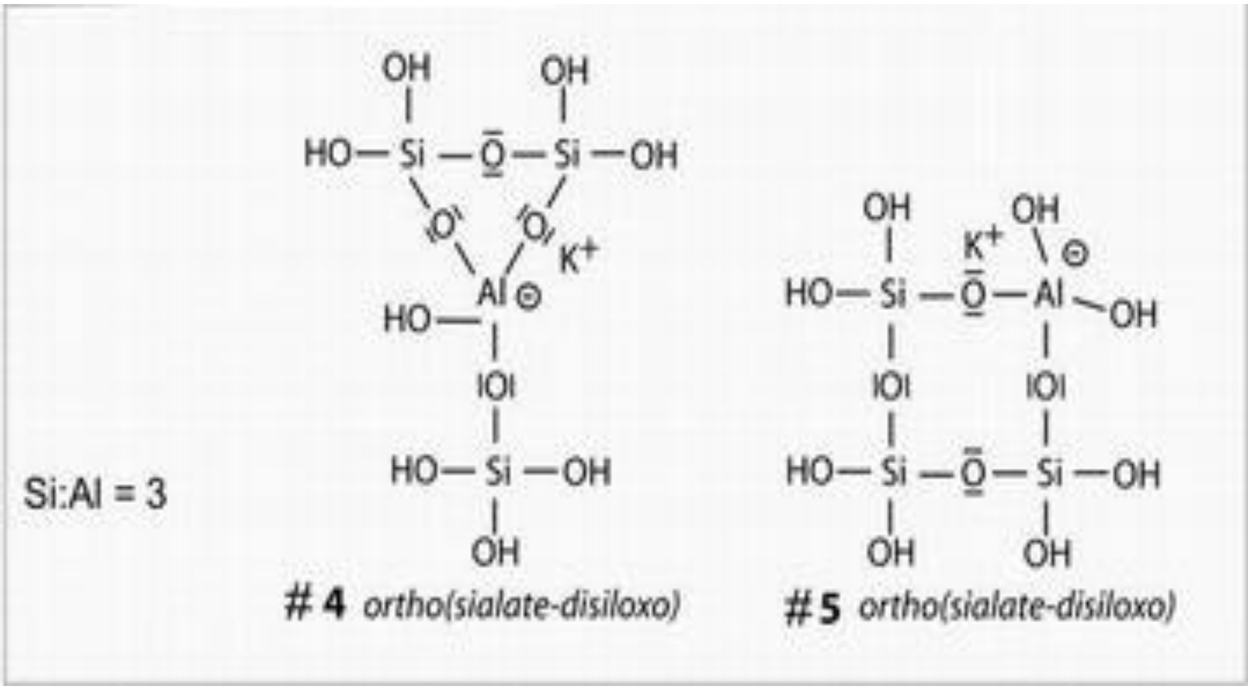


Fig 2 Typical Geopolymer (schematic)

<u>Photos 1 Precast Products at CASHUTEC, Raichur, Karnataka</u>

Production of Blocks using GPT

Exposure to Engineering Students on GPT

Sl. No.	Product Name	Size In mm
1	Standard size Brick	230 x 100 x 75
2	Solid Block	400 x 150 x 200
3	Solid Block	300 x 200 x 125
4	Solid Block	400 x 200 x 200
5	Ventillator	600 x 600
6	Hexagonal paver	300 x 300
7	Zigzag paver	230 x 110
8	I SHAPE PAVER	230 x 110
9	Nut bolt sytem Garden bench	1500 x 600
10	Fencing pole	2100 x 150 x 150
11	Kerb stone	600 x 300 x75
12	Compound wall cladding	1800 x 300 x 50
13	Interlocking columns	2400 x 150 x 150
14	Sanitary rings	900 x 300
15	Kilometer stone	1200 x 750 x 300
16	Name board	450 x 230 x 50
17	Guard stone	1200 x 150 x 150
18	Linetel/Chejja	1200 x 600
19	Saucer Drain	600 x 300 x 100
20	Tree Guard	1200 x 600 x 50
21	Kerb stone	450 x 450 x 150
22	Ring cap	1200 x 50

23. Precast toilet blocks
24. Door frame
25. Window frame
26 brick type paver
27 flower shaped paver
28 Hexagonal paver
29 Hexagonal paver with centre hole
30 flower shaped paver with centre hole
31. Drain cover slab
32. Cover block
33. Name board (big size)

A Brief List of Precast GPC Products made

****

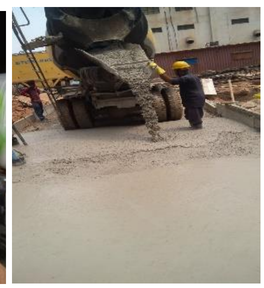
Photos 2 GPC Road making at Raigad, Chhattisgarh

Img5 220mm slump without segregation

Img6 GP concrete casting at plotted area

60mm Needle Vibrator used for concreting

Surface levelling of GP Concreting After 15 hrs of casting



****

Photos 3 GPC Field Trials at SRMIST

****

Photos 4 GPC Pavers at Commercial Concrete Block Production Plant, Chennai

****

Photos 5 GPC Block Production on Egg Laying Block Making Machine, Chennai

****

Geopolymer composites to cater the needs of costal area producing the same by using marine water

Venu Madhav
Principal, Audisankara Institute of Technology, Gudur (A.P)

India is one of the Developing countries that needs to face the environmental pollution. We have many ways to reduce environmental pollution that causes by production of Portland cement and by the increasing of waste material. Geopolymer is the term used to represent the binders produced by polymeric reaction of alkaline liquid with silicon and aluminium as source materials. Common river sand is expensive due to excessive cost of transportation from natural sources. Also large-scale depletion of these sources creates environmental problems. River sand is most commonly used fine aggregate in the production of concrete poses the problem of acute shortage in many areas. In such a situation the Quarry rock dust can be an economic alternative to the river sand. Quarry Rock Dust can be defined as residue, tailing or other non-voluble waste material after the extraction and processing of rocks to form fine particles less than 4.75 mm. This paper presents the feasibility of the usage of Quarry Rock Dust as a substitute for Natural Sand in geopolymer mortar. The by-product materials considered in this study are combination of GGBFS and Fly ash. The experimental program involves casting of geopolymer mortar cubes by using GGBFS, Flyash and Quarry rock dust and testing them at 1 day, 3 days and 7 days for compressive strength. Different parameter considered in this study is alkaline fluid to binder ratio Keeping 12-Molarity of the alkaline liquid and the ratio of sodium hydroxide to sodium meta silicate as constant (1:2). Based on the above study, inferences were drawn.

The strength increased with increase in age, increase in percentage of GGBFS and also with an increase in Fluid (F) to Binder (B) ratio. Thus we can say that there is consistent increase in strength for an increase in F/B from 0.5 to 0.55 but the strength has greatly reduced when the F/B is further decreased, which shows the scarcity of fluid cannot impart strength due to weak activation.

Mechanical Properties of Geopolymer Concrete with Alternative Materials

Vinod Sasalatti[1], and Radhakrishna[2]

[1]Research Scholar, R V College of Engineering, Bangalore -560059
[2]Professor and Head, Dept of Civil Engg, R V College of Engineering, Bengaluru -560059, affiliated to Visvesvaraya Technological University, Belagavi.
Email: radhakrishna@rvce.edu.in, Ph: +91 9886127398

Abstract

Concrete is considered the world’s best versatile, durable and reliable construction material which is next only to water. It is the most consumed material requiring large quantity of cement, fine aggregates, course aggregates and water. Constituents of concrete can be replaced partially or fully with alternate materials to make geopolymer concrete. The present study focuses on sustainable geopolymer technology of making concrete using industrial wastes ie, Class F fly ash, GGBS, Metakaolin and Bagasse ash, M-sand, Pond ash, Recycled aggregates and Recycled water and their effects on mechanical properties. The combination of these materials has yielded interesting and encouragable results.

Key words: Geopolymer, fly ash, GGBS, Bagasse ash, Sustainability.

Introduction

Concrete, a composite material is the second most consumed in the world after water and is a versatile material that can be molded into almost any shape [1]. Manufacture of cement involve high energy consumption and emits greater amount of CO_2 during production [2]. Extraction of natural sand (sand) from river beds results in loss of vegetation on river banks and lowering of ground water table [3]. Ecological imbalance, increased cost of transportation and construction are caused by use of cement, sand and coarse aggregates. Extensive use of traditional materials of cement concrete (CC) results in their faster depletion and cause several disadvantages and affects the environment. It is important to address the problems effectively by finding alternate materials to reduce or completely replace traditional materials to save the environment [4]. Some of the alternative materials that can be used as replacement of cement, fine aggregate and coarse aggregate are fly ash, ground granulated blast furnace slag (GGBS), bagasse ash, rice husk ash, coconut shell, M-sand, foundry sand, pond ash, blast furnace slag, recycled aggregates and recycled water etc. In this study geopolymer concrete is prepared by replacing the ingredients ie, binder, fine aggregate, coarse aggregate and water with alternative materials.

Geopolymer acts as a binder to bind the aggregates in geopolymer concrete (GPC). It is formed when silica and alumina present in base material are activated by combination of sodium silicate and sodium hydroxide solution at high alkanility. Geopolymer concrete has better sulphate resistance, acid resistance and undergoes less creep [5]. Bagasse ash (BA) is the by-product of sugar refining industry and is a pazzolonic material with 85-90 % of silica and alumina [6]. Slag sand (SS) is a by-product produced in the process of iron making in blast furnace which is mildly alkaline and doesn't pose risk of corrosion to steel in concrete and also reduces cost of concrete [7]. Recycled aggregates (RA) are produced from crushing the concrete waste of demolished buildings to a required size.

A study has revealed that, compressive strength of geopolymer concrete increases with increase in concentration of sodium hydroxide in terms of molarity, sodium silicate to sodium hydroxide ratio, curing temperature and curing time. [8, 9]. Optimum compressive strength was achieved for sodium silicate to sodium hydroxide ratio of 2.5 and molarity of 12M. Increase in molarity decreases workability of geopolymer concrete [10, 11, 12]. Also, workability increases with increase in fly ash content and alkaline-binder ratio in geopolymer concrete [13]. Improved workability was noticed when M-sand was used in geopolymer concrete [14, 15]. Compressive and split tensile strengths decrease with increase in fly ash content [10, 16]. Increased replacement of bagasse ash in concrete resulted in decreased workability and compressive strength [17]. The properties of geopolymer concrete improved when sand is replaced with M-sand up to the level of 60 % [18]. Increased replacement of sand by pond ash decreased the compressive strength but increased flexural strength at the optimum replacement of 20 - 30 % [19, 20]. Maximum compressive strength was achieved at 25 to 50 % replacement of sand with slag sand [21]. With increased replacement of coarse aggregate by recycled aggregate, decrease in compressive, split tensile and flexural strengths was observed [22]. The properties of geopolyers with specific combinations of flyash, baggase ash and GGBS are not much reported in the literature. The present research is an approach to find possible alternative materials for making geopolymer concrete as an alternative to cement concrete. Alkaline solution of 12 M with sodium silicate to sodium hydroxide ratio 1.25:1 and fly ash to GGBS ratio of 80:20 are considered for making geopolymer concrete based on the referred literature [8, 9]. Objective of the study is to characterize the materials, check their suitability for making geopolymer concrete and to study the workability and mechanical properties of geopolymer concrete using alternative materials.

Materials and Methods

Flyash and pond ash (PA), GGBS, slag sand (SS) and bagasse ash (BA) were procured from RTPS, Shaktinagar, Raichur, Jindal Steel works, Bellary and Mandya respectively in Karnataka, India. Commercially available sodium hydroxide, sodium silicate and metakaolin (MK) were used. Natural sand (NS) was procured from Kaveri river bed. Coarse aggregate and M-sand (MS) were procured from Ramnagar. All the materials were characterised for physical properties.

Physical properties of flyash, GGBS, bagasse ash, metakaolin and aggregates are given in **Tables 1** and **2** respectively. Mix combinations of binders, fine aggregates and coarse aggregates and particle size distribution curves for natural sand, M-sand, slag sand, pond ash are shown in **Table 3** and **Figure 1** respectively.

Table 1. Physical properties of Fly ash, GGBS, Bagasse Ash and Metakaolin

Ingredient / Property	Fly ash	GGBS	Bagasse ash	Metakaolin
Specific Gravity	2.3	2.9	2.0	2.6
Residue on 45µ in percentage	0.5	0.5	2.0	0

Table 2. Physical properties of aggregates

Ingradient/ Property	Natural Sand	M-sand	Pond ash	Slag sand	Coarse aggregate	Recycled aggregate
Specific Gravity	2.59	2.5	2.33	2.53	2.62	2.3
Water absorption (%)	0.9	1.8	2	1.2	0.5	3
Grading Zone	III	II	I	II	-	-

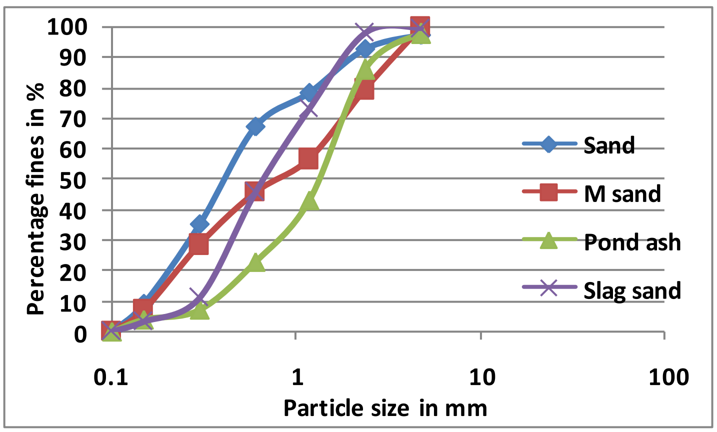


Figure 1. Particle size distribution curves for sand, M-sand, Pond ash and Slag sand

Cement concrete and geopolymer concrete samples with alternative fine aggregates were prepared for binder, fine aggregate and course aggregate in 1:1:2 proportions with fluid-binder ratio of 0.45. The binder was a combination of flyash and GGBS with 80:20 ratio. Alkaline solution of 12 M with sodium silicate to sodium hydroxide ratio of 1.25:1 was considered. Workability of concrete samples in fresh state using slump-cone test and mechanical properties were analysed by replacing fly ash content in the binder with 5% bagasse ash and 5% metakaolin.

Geopolymer concrete was used to cast cubes of size 150x150x150mm and beams of size 100x100x500mm to determine compressive strength and flexural strength respectively as per IS Codes. L-shaped specimens were cast by inserting a wooden block of size 90x60mm in cross section and 150mm in height in 150x150x150mm cube mold. They were tested for shear strength by a method proposed by Baruah and Talukdar [23]. Cylinders of size 150x300 mm were cast to determine split tensile strength. The course aggregate was replaced with recycled aggregate. Modulus of Elasticity was also determined.

Table 3. Mix Combinations of binders, fine aggregates and coarse aggregates

Sample ID	Binder	Fine aggregate	Coarse aggregate	Fluid/ Binder ratio	Slump (mm)
CC	Cement	Sand	Natural	0.45	90
GPC-NS	80%Flyash+ 20%GGBS	Sand	Natural	0.45	110
GPC-SS	80%Flyash+ 20%GGBS	Slag sand	Natural	0.45	85
GPC-MS	80%Flyash+ 20%GGBS	M-sand	Natural	0.45	0
GPC-PA	80%Flyash+ 20%GGBS	Pond Ash	Natural	0.45	0
GPC-BA	75%Flyash+ 20%GGBS + 5%Bagasse ash	Sand	Natural	0.45	20
GPC-MK	75%Flyash+20%GGBS+ 5%Metakaolin	Sand	Natural	0.45	40
GPC-RA	80%Flyash+ 20%GGBS	Sand	Recycled	0.45	0

Results and discussion

Table 4 and **Figure 2** give the compressive strength of cement concrete and geopolymer concrete with alternative binders. The reduction in strength of geopolymer concrete was observed when 80 % fly ash was replaced with 75 % fly ash and 5 % bagasse or 5 % metakaolin. The reduction in strength is 1.7 % and 3.5 % respectively. With respect cement concrete the compressive strength of geopolymer concrete was found 28 % lesser. As per earlier studies, similar results were achieved when cement was replaced with 5 % alternative binders such as bagasse ash and metakaolin in cement concrete [17, 24].

Table 4. Compressive strength of cement concrete and geopolymer concretes with alternative binders.

Sample ID	28 days Compressive strength (in MPa)	Remarks
CC	32.1	Not Applicable
GPC	23.1	28 % less than CC
GPC-BA	22.7	29 % less than CC and 1.7% less than GPC
GPC-MK	22.3	31 % less than CC and 3.5% less than GPC

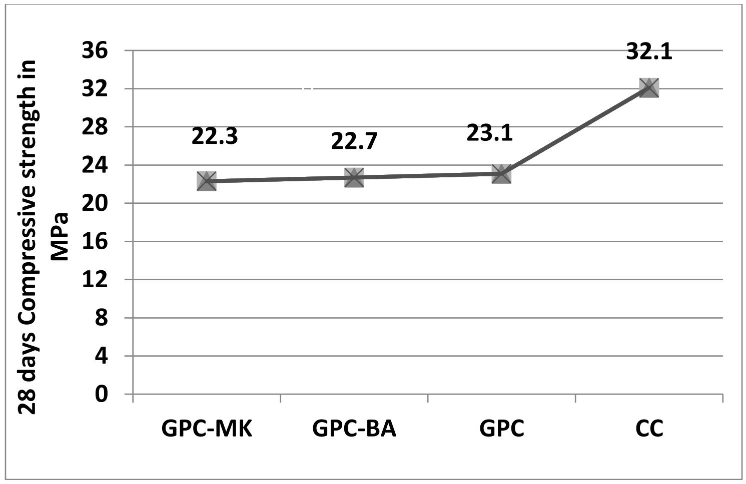


Figure 2. Compressive strength of CC and GPC with different binders

Table 5 shows the density and compressive strength of geopolymer concrete with alternative fine aggregates. There was not much variation observed in case of densitty cement concrete and geopolymer concrete with different aggregates. The compressive strength of cement concrete after 3 days and 7 days was more compared to geopolymer concrete with alternative fine aggregates. This low early strength of geopolymer concrete is due to slower polymerization during initial stages. There is a gradual increase in compressive strength of geopolymer concrete for fine aggregates ie., from pond ash to natural sand to slag sand and M-sand.

Table 5. Density and compressive strength of CC and GPC with alternative fine aggregates

Sample ID	Density after 28 days in Kg/m^3	Compressive strength in MPa		
		3 days	7 days	28 days
CC	23.25	14.67	22.6	32.10
GPC-NS	22.67	2.31	3.3	23.11
GPC-MS	22.64	2.48	4.09	25.33
GPC-SS	22.81	2.52	3.82	24.70
GPC-PA	22.38	2.50	3.7	21.04

Table 6 shows the compressive strength of cement concrete and geo-polymer concrete with coarse aggregates and recycled aggregates.
There was 26 % reduction in strength when recycled aggregate was used with cement concrete as compared to cement concrete with natural aggregate. Reduction in strength was 29 % for geopolymer concrete compared to cement concrete both recycled aggregate. This is due to higher water absorption by recycled aggregates in concrete [25, 26].

Table 6. Compressive strength of CC and GPC with recycled coarse aggregates

Sample ID	28 days Compressive strength in MPa	Remarks
CC	32.0	Not applicable
CC-RA	23.5	26 % less than CC
GPC-RA	16.6	48 % less than CC 29 % less than CC-RA

Split tensile strength for cement concrete is around 10 % of compressive strength and same was observed for geopolymer concrete with various fine aggregates. **Table 7** gives Split tensile strength of cement concrete and geopolymer concrete with alternative fine aggregates. Split tensile strength of geopolymer concrete was found maximum and minimum for M-sand and pond ash respectively.

Table 7. Split tensile strength of CC and GPC with alternative fine aggregates

Sample ID	Split tensile strength in MPa	Remarks
CC	3.49	Not applicable
GPC-NS	2.45	30% less than CC
GPC-MS	2.82	19% less than CC & 15% more than GPC-NS
GPC-SS	2.58	26% less than CC & 5% more than GPC-NS
GPC-PA	2.17	38% less than CC & 11% less than GPC-NS

Table 8 shows flexural strength of cement concrete and geopolymer concrete with alternative fine aggregates. According to IS 456:2000, flexural strength should be $0.7\sqrt{f_{ck}}$ which is equal to 3.5 MPa for M 25 grade concrete. The flexural strength obtained for concrete with various combinations was more than 3.5 MPa. Geopolymer concrete with M-sand and pond ash showed highest and lowest flexural strength respectively.

Table 8. Flexural strength of CC and GPC with alternative fine aggregates

Sample ID	Flexural strength in MPa	Remarks
CC	4.44	NA
GPC-NS	4.06	8.5% less than CC
GPC-MS	4.22	5% less than CC & 4% more than GPC-NS
GPC-SS	4.14	6.8% less than CC & 2% more than GPC-NS
GPC-PA	3.77	15% less than CC & 7% less than GPC-NS

Table 9 shows shear strength of cement concrete and geopolymer concrete with alternative aggregates. Geopolymer concrete has good shear strength and the strength values obtained are similar to earlier study [23]. Geopolymer concrete with M-sand has higher shear strength compared to geopolymer concrete with slag sand and pond ash.

Table 9. Shear strength of CC and GPC with alternative fine aggregates

Sample ID	Shear strength in MPa	Remarks
CC	9.5	
GPC-NS	7.81	17.8% less than CC
GPC-MS	8.67	8.7% less than CC & 11% more than GPC-NS
GPC-SS	7.25	23% less than CC & 7% less than GPC-NS
GPC-PA	6.85	27.8% less than CC & 12.3% less than GPC-NS

Variation of stress with strain is shown in Figure 5. It was observed that the variation of stress with respect to strain is not linear and found similar to cement concrete. Among Geopolymer concrete with various fine aggregates, geopolymer concrete with M-sand has maximum modulus of elasticity than with natural sand, slag sand and pond ash.

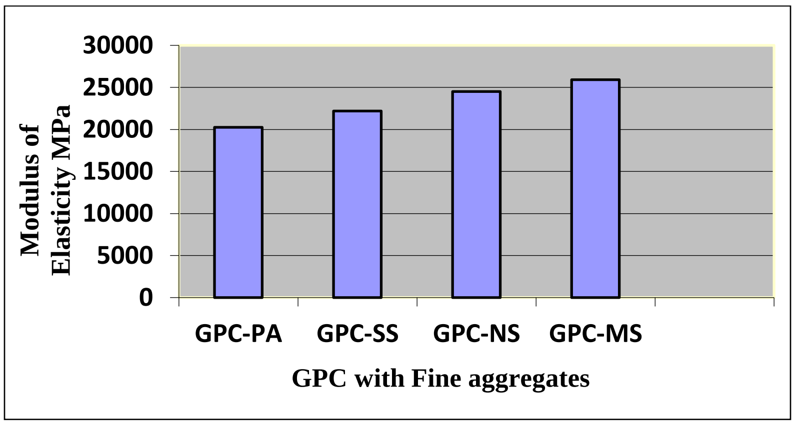


Figure 5. Modulus of Elasticity of GPC with various aggregates

Conclusions

Following conclusions are drawn by the study on cement concrete and geopolymer concrete with alternative materials.

- Slump value for geopolymer concrete with natural sand is more than cement concrete.
- Workability of geopolymer concrete decreases when alternative binders such as bagasse ash and metakolin are used even in small percentages. The workability of geopolymer concrete is better with natural sand and slag sand among the various fine aggregates.
- Compressive, split tensile, flexural and shear strengths of geopolymer concrete with M-sand and slag sand are higher than the geopolymer concrete with natural sand and pond ash.
- Compressive strength of geopolymer concrete with recycled aggregates is very low compared to geopolymer concrete with natural aggregates.

- Air cured geopolymer concrete with various fine aggregates and alternative binders at lower replacement levels can be used as structural concrete and total sustainability can be achieved.

Acknowledgement

The authors would like to thank the authorities of R V College of Engineering, Bengaluru for their support and encouragement.

References

1. Sunil Kumar, R and Ramesh, V., “Study on Behaviour of Geopolymer Concrete”, International Journal of Civil and Structural Engineering Research, Vol. 3, Issue 1, Sep 2015, pp 384-388.
2. Gautam L, Prema Apeksha Kanojia and Jain S. K., “Performance of Coconut Shell as Coarse Aggregate in Concrete: A Review”, International Research Journal of Engineering and Technology (IRJET), Vol. 2, Issue 04, July 2015, pp 1096-1100.
3. Vipul Naidu, P. and Pawan Kumar Pandey, “Replacement of Cement in Concrete”, International Journal of Environmental Research and Development, ISSN 2249-3131 Vol. 4, Number 1, 2014, pp 92-98.
4. Subramani, T. and Ramesh, K.S., “Experimental Study on Partial Replacement of Cement with Fly Ash and Complete Replacement of Sand with M sand”, International Journal of Application or Innovation in Engineering & Management (IJAIEM), Vol. 4, Issue 5, May 2015, pp 313-322.
5. Sonali, K., Gadpalliwar, Deotale, R. S. and Abhijeet, R. Narde, “To Study the Partial Replacement of Cement by GGBS & RHA and Natural Sand by Quarry Sand In Concrete”, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), Vol. 11, Issue 2, Ver. II, Mar- Apr. 2014, pp 69-77.
6. Ushaa, T. G., Anuradha, R., Venkatasubramani. G. S., “Performance of self-compacting geopolymer concrete containing different mineral admixtures”, Indian Journal of Engineering & Materials Sciences, Vol. 22, August 2015, pp. 473-481.
7. Bagwan, K. M. and Dr. Kulkarni, S. S., “A Study of Characteristic and Use of Pond Ash for Construction”, International Journal of Emerging Technology and Advanced Engineering, Vol. 4, Issue 6, June 2014, pp 835-840.
8. Sujata, D. Nandagawali and Dhamge, N. R., “Study of Blast Furnace Slag for Improving Mechanical Property of Concrete”, International Journal of Engineering Science and Innovative Technology (IJESIT) Vol. 3, Issue 4, July 2014, pp 473-477.
9. Rajini. B and Narasimha, Rao, A.V., “Mechanical properties of a Geopolymer Concrete with Fly ash and GGBS as source materials”, International Journals of Innovative Research in Science, Engineering and Technology, Vol. 3, Issue 9, September 2014, pp 15944- 15953.
10. Ravi Kumar, V. and Mani, P., “An Experimental Study on Fly ash Based Geopolymer Concrete”, International Journal of Engineering Sciences and Research Technology, Nov. 2015, pp 240-246.
11. Manoj Kumar Manugunta and Naveena Kanaboyana., “Experimental Studies on Strength characteristics of 12M Geopolymer Mortar Based on Flyash and GGBS”,

International Journal of Innovations in Engineering and Technology, Vol. 4, Issue 5, May 2015, pp 2911- 2919.

12. Mohammed Areeb Qidwai, Abid Alam, Imran Alam, "The Effect Of Molarity on Geopolymer Concrete", International Journal of Advanced Engineering Research and Studies, Apr-Jun 2015, pp 9-12.
13. Shaik Jabiulla and Neeraja D., "Performance Evaluation of Metakaolin And Flyash Based Geo Polymer Concrete", International Journal For Technological Research In Engineering Vol. 2, Issue 7, March 2015, pp 1309- 1312.
14. Chandan Kumar ., Krishna Murari., Sharma, C. R., "Performance Of Geopolymer Concrete At Elevated Temperature And Against Aggressive Chemical Environment", International Journals Of Innovative Research In Science, Engineering And Technology, Vol. 3, Issue 6, June 2014, pp 13366- 13373.
15. Vijaya Sekhar Reddy, M., and Vamsi Krishna Reddy, S., "Geopolymer Binder By Using Fly Ash", International Journal Of Advanced Scientific And Technical Research, Vol. 3, Issue 4, May-June 2014, pp 891-896.
16. Khalid Bashir., "Fly Ash Based Geo Polymer Concrete", IOSR Journal of Mechanical and Civil Engineering, 2014, pp 19-23.
17. Srinivasan R and Sathiya K., "Experimental study on Bagasse ash in Concrete", International Journal for Service Learning in Engineering, Vol. 5, 2010, pp 60-66.
18. Parthiban, K. and Vaithianathan, S., "Effect of Kaolin Content and Alkaline Concentration on the Strength Development of Geopolymer Concrete", International Journal of ChemTech Research, Vol. 8, No.4, 2015, pp 1730-1734.
19. Krishnan,L., Karthikeyan,S., Nathiya,S. and Suganya, K., "Geopolymer Concrete An Eco Friendly Construction Material", International Journal of Research In Engineering and Technology, Vol. 3, Issue 11, Jun 2014, pp 164-167.
20. Srinivas, K.S., Prathap Kumar, M.T. and Prema Kumar, W. P., "Comparative Performance of Geopolymer Concrete Exposed To Acidic Environment", Vol. 4, Issue 4, May 2015, pp 27-31.
21. Vignesh, P and Vivek, K., "An Experimental Investigation on Strength Parameters of Fly Ash Based Geopolymer Concrete with GGBS", Vol. 2, Issue 2, May 2015, pp 135 -142.
22. Rohit Zende and Mamatha, A., "Study On Fly Ash and GGBS Based Geopolymer Concrete under Ambient Curing", Journal of Emerging Technologies and Innovative Research, Vol. 2, Issue 7, July 2015, pp 3082- 3087.
23. Baruah, P. and Talukdar, S., "A Comparative study of Compressive, Flexural, Tensile and Shear strength of concrete with fibers of different origins", Indian Concrete Journal, July 2007, pp 17-24.
24. Yogesh, R., Suryawanshi Amar, G., Kadam Sagar, S. Ghogare, Ramrao G. Ingale, and Priyanka L. Patil," Experimental Study on Compressive Strength of Concrete by Using Metakaolin", International Research Journal of Engineering and Technology, Vol. 2, May 2015, pp 235-239.
25. Fathei Ramadan Salehlamein, Mochamad Solikin and Srisunarjono., "Effect of Recycled Coarse Aggregate on Concrete Properties", International Journal of Innovative Research in Science, Engineering and Technology, Vol. 4, Issue 1, January 2015, pp 19060-19068.

26. Manjunath, M. and Prakash, K.B., "Effect of replacement of natural aggregates by recycled aggregates derived from field demolished concrete on the workability and strength characteristics of concrete", International journal of environmental sciences, Vol. 6, 2015, pp 119-128.

Alkali Activated fly Ash based Geo-Polymer Concrete for Infrastructure Applications

S.K. Singh

CSIR-Central Building Research Institute, Roorkee – 247667, India; sksingh_cbri@yahoo.co.in

Abstract

Geopolymer is an inorganic aluminosilicate binder that can be used as an alternative to Ordinary Portland Cement. This alternative inorganic binder chemistry has been investigated extensively in the laboratory to develop geopolymer matrices and concrete materials laid on scientifically sound basis. Significant progress has been made in the development and applications of geopolymers during the recent decades. An overview of advances in geopolymers formed by the alkaline activation of aluminosilicates is presented in this paper. The technological and commercial potentials and opportunities were also outlined in the paper. The challenges faced in the up scaling and implementation of the geopolymer concrete in construction and other various less well known niches of applications are described briefly. The research and development carried at CSIR-CBRI, Roorkee is presented with developed various products using geopolymer concrete at the Institute with pilot scale trials.

INTRODUCTION

The use of alternative binders in place of ordinary Portland cement (OPC) have gained strong basis recently due to the increasing focus on global climate change, the public and consumer preferences for “green” products, and the associated markets in carbon credits. These alternative binding systems can provide a viable direct opportunity for near term and substantial CO_2 emissions reduction. There are a variety of binder systems available that deliver the potential for high performance and environmental savings, while representing a significant departure from the traditional chemistry of OPC. The demand of green concrete in construction industry is driven by increased regulations to reduce carbon footprint, limit greenhouse gas emission and shortage of landfill sites. Increasing emphasis on energy conservation and environmental protection has led to investigations on alternatives to conventional building materials. In this regard, a potential alternative to Portland cement is geopolymer. The term “geopolymer” is generically used to describe the amorphous to crystalline reaction products from the synthesis of alkali aluminosilicates with alkali hydroxide/alkali silicate solution. There are several advantages of geopolymer materials over OPC, namely potential environmental benefits, high compressive strength, rapid setting and hardening, fire resistance, and acid and salt solution resistance reported in the literatures. One of the most important benefits of geopolymers lies in the utilization of industrial wastes as resource raw materials. In terms of their environmental impact, geopolymers are reported to generate nearly 80% less CO_2 than OPC.

However, this green binder constrained from full scale application because of the key gaps in one or more of the following areas: (a) validated long term durability data (b) appropriate regulatory standards and accompanying awareness from regulatory authorities regarding the state of technological maturity (c) industrial and commercial experience in materials design, production, quality control and placement; (d) raw materials supply chain [1].

The national and global geopolymer market is projected to witness robust growth throughout the upcoming period. The rising focus of key players on technological developments and innovations is one of the vital factors estimated to encourage the growth of global geopolymer market in the next few years. In addition, the expansion of application base is expected to generate promising opportunities for the key players operating in the geopolymer market. With the help of these drivers, the geopolymer market is expected to register an impressive growth.

The commercial future of alkali activated geopolymer materials, similar to the case of many other alternative binders for concretes, depends not only on technical readiness, but also on the economic and social readiness. Standardization is an important component of commercialization, but in fact (and contrary to the assumptions of many researchers) represents only a small part of the whole commercialization process.

The aim of this paper is to provide a comprehensive review on the process of synthesis of geopolymer binder and to briefly describe the research studies reported on the geopolymer concrete in construction. Various possible applications of geopolymer concrete have been presented along with the challenges faced by the promoters and commercialization agencies for large scale construction and implementation.

GEOPOLYMER SYNTHESIS

Geopolymers are the subset of alkali activated materials (AAM), where the binding phase is almost exclusively aluminosilicate and highly coordinated [2]. To form such a gel as the primary binding phase, the available calcium content of the reacting components is usually low, to enable formation of a pseudo-zeolitic network structure rather than the chains characteristic of calcium silicate hydrates[3]. The activators are usually alkali metal hydroxide or/and silicate. Low-calcium fly ashes and calcined clays are the most prevalent precursors used in geopolymer synthesis [4]. The fundamental binder structure in low-calcium alkali-activated systems is known to be a highly disordered, highly cross-linked aluminosilicate gel. Both Si and Al are present in tetrahedral coordination, with the charges associated with tetrahedral Al sites balanced through the association of alkali cations with the gel framework. Similarities between this gel structure and the structure of zeolites have been cited in numerous publications. This includes the early research work of

Glukhovskyet al. [5], who used zeolitic structures to draw an analogy between alkali-activated binders and ancient Roman concretes. Davidovits [6], who sketched molecular structure fragments based on the zeolitic or similar structures (analcime, sodalite, phillipsite, leucite, kalsilite). Later, itwas proposedthe similarity between hydrothermal zeolite synthesis and the synthesis of alkali aluminosilicatebinders [7]. This leads to generation of nanosized zeolite-like structural units throughout the AAM gel in addition to crystalline zeolites, which are widely observed, embedded within the disordered gel, particularly at higher curing temperatures [8].

The geopolymerization process involves three separate processes and during initial mixing, the alkaline solution dissolves silicon and aluminium ions in the raw material (fly ash, slag, silica fume, bentonite etc.). It is also understood that the silicon or aluminium hydroxide molecules undergo a condensation reaction where adjacent hydroxyl ions from these near neighbours condense to form an oxygen bond linking the water molecule, andit is seen that each oxygen bond is formed because of a condensation reaction and thereby bonds the neighboring Sior Al tetra-hedra [9].Fig. 1 presents a highly simplified reaction mechanism for geopolymerization. Thisoutlines the key processes occurring in the transformation of a solid alumino-silicate source into a synthetic alkali aluminosilicate [4].

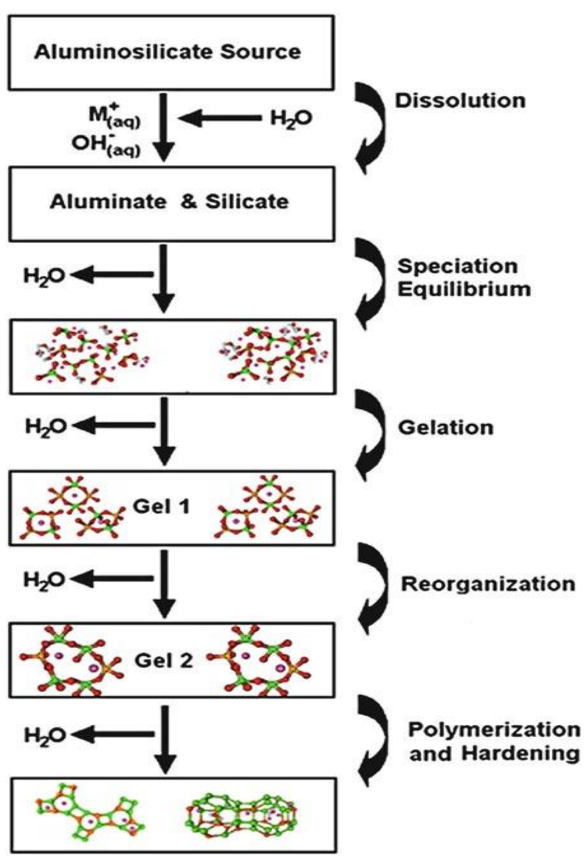


Fig. 1. Synthesis of geopolymer binder by hydroxide activation of an aluminosilicate source [4].

The of geopolymerization mechanism composed of conjoined reactions of destruction/dissolution–coagulation–condensation–crystallization.The first step consists of a breakdown of the covalent bonds Si–O–Si and Al–O–Si, which happens when the pH of the alkaline solution rises ,so those groups are transformed into a colloid phase. The dissolution step is affected by several factors which includes temperature, pH and the possible pretreatments of the aluminosilicate source. An accumulation of the destroyed products occurs, which interacts among them to form a coagulated structure, leading in a third phase to the generation of a condensed structure and crystallized.

APPLICATIONS/ PRODUCTS DEVELOPMENT

Early research in the developments of geopolymer (low-calcium including calcium-free) binders were led by Davidovits in France. These materials were initially envisaged as a fire-resistant replacement for organic polymeric materials, with identification of potential applications as a possible binder for concrete production [10]. However, developments in the area of concrete production soon led back to more calcium-rich systems, including the hybrid binders, leaving work based on the use of low-calcium systems predominantly aimed at high-temperature applications and other scenarios where the ceramic-like nature of clay-derived alkali- activated pastes was beneficial. Geopolymer cement is an innovative material and a real alternative to conventional Portland cement for use in construction, transportation infrastructure and offshore applications.

Application as structural members

The applicability and suitability of geopolymer concreteas structural element, design aspects such as loadcarrying, flexural strength and bond-slip were studied and assessed. Therefore, applications of geopolymer concrete were extended to structural elementssuch as beams, columns and slabs. The structural behaviour of fly ash-based geopolymer concrete beam similar to the ordinary reinforced concrete beams [11]. Ng et al. [12] found better performance of geopolymer concrete beams with steel fibers. The shear cracks were delayed due to addition of fiber. It was reported that lower post-peak ductility was observed when ground granulated blast furnace slag (ggbfs) were added in geopolymer concrete [13]. Failure mode of fly ash based geopolymer concrete column was observed similar to conventional concrete column [14]. Brittle failure was reported of geopolymer concrete columns [11]. To increase the load carrying capacity and the ductility of steel fibers and confinement can be used. While in geopolymer concrete slabs, it was found that the ductility and energy absorption are better compared to ferro-cement slabs [15,16].

Application as porous/insulating material

Research studies were carried out on the development of porous geopolymer particularly as insulating materials for potential building applications. The foamed agents includes air foaming generator, sodium perborate, hydrogen peroxide, aluminum powder, and biomass materials were used [17- 21]. Abdollahnejad et al. [17] investigated the joint effect of several mix parameters on the properties of fly ash-based foam geopolymers and observed a better result with sodium perborate compared to hydrogen peroxide as a foaming agent. A mixture with a low thermal conductivity of 0.1 $W(m\ K)^{-1}$ and compressive strength of 6 MPa was obtained, suggesting the potential use of the foamed fly ash geopolymeras insulating materials for building applications [17].In addition to insulating applications, porous or absorbent geopolymers were also developed with or without foaming agents, for potential application in purification [22,23].Pilot-scale production of autoclaved foamed alkali-activated GGBFS concrete was initiated in 1978 in Berezovo, Russia, using a waste mixed-alkali hydroxide solution as an activator[24]. Later, in Kiev the development of autoclaved aerated concretes by alkaline activation of metakaolins and fly ashes were carried out [25,26].

Applications as fire resistant/ protection materials

Several researchers [27-30] carried out the development of geopolymers for fire resistant lining / coating applications. Reflective heat insulation coating was prepared using a geopolymer, which was mainly made of sodium silicate solutions and metakaolin as the primary film forming material before adding, after screening their functions, sericite powder, talcum powder, titanium dioxide and hollow glass microspheres as fillers. This coating presented many capabilities, such as good water-retention, simple spraying, high durability and dirt resistance, with a reflectivity above90% and a thermal insulation temperature difference reaching 24ºC, suggesting its potential use in buildings to conserve energy [28]. Geopolymer coating can also be applied as surface protection to concrete structures in order to extend their service life [29,30].

For fire resistant applications there are two distinct product types: those that are to be used as structural components (tunnels, walls, etc.), and those that will be used as coatings to insulate structural steel beams or other items. The first type requires high compressive strength over a wide temperature range so the structure is not compromised, while the second type needs high adhesion to a substrate and must be lightweight. Wear resistance rather than mechanical strength is important in coating applications [1]. Extensive research hasbeen carried out on the assessment of thermal properties of geopolymer materials. Kong and Sanjayan [31] showed that fly ash-based geopolymer is consolidated further whenexposed to elevated temperatures up to 800 °C. Metakaolin geopolymers prepared with sodiumor potassium alkaline reagents were reported to be fire resistant, with thermal stability up toabout 900 °C [32,33]. Geopolymer concrete have been observed to offer an advantage over OPC of significantly reduced spalling and superior mechanical strength retention after exposure to fire [34]. Applications for fire-resistant products include tunnel linings, high rise buildings, lift doors and marine structures/coatings [35].

Specialized geopolymer formulations are also suitable for refractory applications, where their low cost and acceptable performance at moderately high temperatures can provide advantages over other available materials [36–38]. Low water content and high-purity geopolymer suits industrial refractory applications where the material may be subjected to temperatures in excess of 1,200 °C.

A number of authors have also made use of the foaming tendencies of partially-polymerised-aluminosilicate gels at elevated temperature to develop geopolymer materials which expand into a foam at elevated temperature [39–41]. This property has been noted to be of value in passive fire prevention applications [42], as it is endothermic and also leads to the generation of a space-filling incombustible foam material.

Application as pre-cast members

The Melton Library in Melbourne consists of 3,500 m^2 of floor space over two levels and has been made from 40 MPa geopolymer concrete designed for high early strength with focus on sustainable construction. 35 precast panels of 9 m long of geopolymer concrete were installed in 2012 as exterior façade of the building as shown in Fig. 2. Another obvious civil infrastructure-related application for geopolymer concrete are in precast applications as shown in Fig. 3. In addition, prestressed railways sleepers meeting the national standards of Japan have been produced on a laboratory scale by alkali-silicate activation of fly ash [43]. Alkali-activated slag sleepers were also developed in Poland, reaching the required 70 MPa strength through the use of finely ground slag [44], and providing performance reported as being equivalent to that of Portland cement sleepers during a 5-year service period [45]. A pilot-scale research and development program in Spain [46, 47] led to the development of pre-stressed steam-cured sleepers based on alkali hydroxide-activated fly ash, which were able to meet the requirements of Spanish and European specifications for such products.

Fig. 2: Precast geopolymer concrete panels for Melton Library, Melbourne, Australia

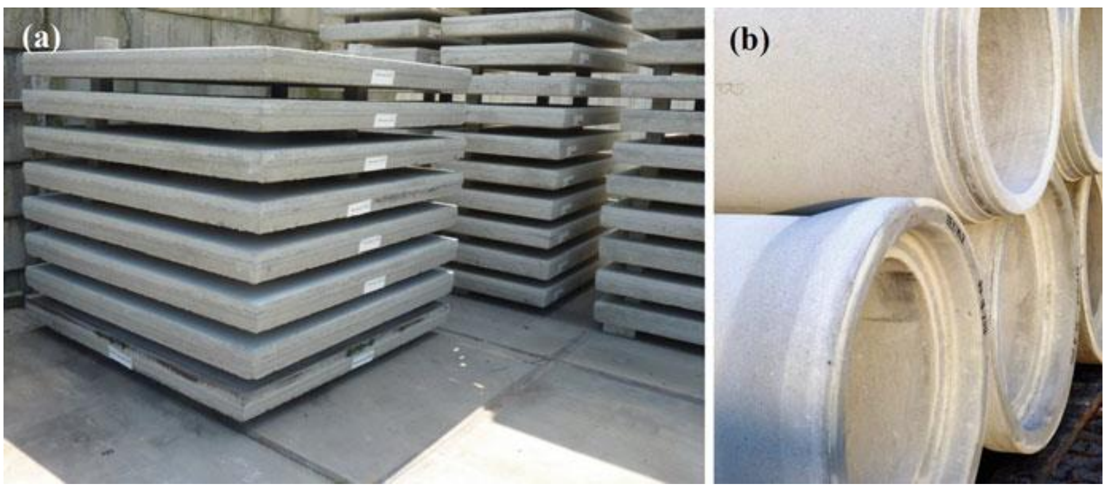


Fig. 4. Precast Geopolymer concrete products (a) slabs; (b) pipes

In addition to the civil infrastructure-related applications, there are a number of areas in which geopolymer chemistry has been shown to provide the potential for utilization in niche applications in various areas of civil and materials engineering. It is unlikely that any specific binder formulation will show all of the properties. It is also possible to tailor materials for applications in lightweight materials production, as a well for underground construction, for high-temperature applications, as a stabilisation/solidification matrix for hazardous or radioactive wastes.

Zeobond Group in Melbourne, Australia commercialized geopolymer concrete since 2006. It has developed a geopolymer binder branded as the E-Crete™, which is generally produced from blends of fly ash, slag and alkaline activators. This is mixed with sand and aggregate in similar proportions to traditional cement binders to form concrete. The life cycle analysis of geopolymer binder were compared to the standard OPC blends which showed an 80 % reduction in CO_2 emissions, whereas the comparison on a concrete-to-concrete basis showed slightly greater than 60 % [1]. Several applications are shown in Fig. 4 and Fig. 5.

Fig. 4:E-Crete pre-cast footpath at Salmon Street bridge in PortMelbourne, Australia

Fig. 5:E-Crete retaining wall at the Swan Street bridge in Melbourne, Australia

RESEARCH AND DEVELOPMENT AT CSIR-CBRI

CSIR-CBRI, Roorkee has pioneered in study on fly ash based geopolymer in India. The R&D work has been focused on developing geopolymer concrete and building products. The research work carried out to study the effect of various parameters that influences the properties of geopolymer in fresh as well as hardened state. Systematic study on geopolymer paste, mortar and then on concrete has been carried out. Geopolymer with different binder composition, activator type and doses, curing conditions etc. were produced. For large scale in-situ application, an ambient cured geopolymer concrete has been designed with compressive strength ranging from 25 MPa to 60 MPa. Different mechanical and engineering properties were evaluated. Performance of geopolymer concrete was assessed by durability studies under different aggressive environment (acid and sulphate). Alkali-silica reaction test was also carried out to know potential resistance of aggregate in geopolymeric environment. Several building elements like bricks, blocks (solid and hollow), light weight geopolymer foam, sandwich composite and insulation concrete were prepared as shown in Fig. 6. Structural behaviour of the geopolymer concrete beams were also evaluated and compared with Portland cement concrete based on existing design guidelines and was found satisfactory. Indian patent has been filed on this development and process know-how has been licensed to the industry.

(a) (b)

(c)

Fig. 6: Geopolymer products (a) bricks (b) solid blocks (c) reinforced beams

Self-compacting geopolymer concrete is also developed and a pilot scale trial was carried out using concrete pump and mini batching plant as shown in Fig. 7. The concrete was pumped through 150 mm dia. pipe for a length of 100 m. The fresh concrete properties complied the EFNARC guidelines. In-situ strength of the casted column was assessed using NDT through rebound hammer and UPV test was performed to know the quality of cured concrete.

Fig. 7. Self-compacting geopolymer concrete and its casted column

The implementation of the geopolymer technology was done at CSIR-CBRI, Roorkee by laying a 50 m road stretch designed as per IRC/MoRTH specifications. The road stretch was designed for an axial load of 18 tonnes using geotechnical data of the site. Instrumentation of constructed road was also carried out to know temperature differential in top and bottom layer of the geopolymer concrete pavement. The pavement was casted in form of slabs of 4.5 m length jointed through dowel bars for load transfer. The road was tested during casting and also after its construction and found satisfactory. No cracks were observed in the slab. Based on this experience, similar geopolymer road stretch of 100 m length has been constructed as an implementation of the developed technology at NTPC, Dadri. The constructed road is operational and performing well as shown in Fig. 8.

Fig. 8. Geopolymer concrete roads(a) 50 m at CSIR-CBRI, Roorkee (b) 100 m at NTPC Dadri

CURRENT CHALLENGES

The main challenges faced in the wide application and scaled up utilization of geopolymer concrete are as under:

1) Variability in constituent raw materials and its sources: Both quality and quantity of material required vary from place to place and as a result the geopolymer concrete properties differ with the same constituent material. Quality from a single source and most critically, consistency of quality also changes. Not only the base alumino-silicate materials, but also the alkali activators, need to be sourced via a stable and dependable supply chain for a relatively long-time span, to provide a return on the investment required to establish a production facility.

2) Cost economics: Geopolymer materials could become very economically attractive if CO_2taxation, or other pollution-related financial charges are implemented in an effective (global and/or regional) manner, and thus become a serious issue for the building materials industry. The raw materials costs, including slag, fly ash, other natural aluminosilicates and alkali activators, may then be lower than those of OPC clinker if CO_2 taxation is imposed on top of the conventional OPC production cost.

3) Quality control (QC) and quality assurance (QA): Geopolymer concrete productions QA & QC are the most crucial and challenging steps. As most of the operations personnel in a concrete manufacturing facility are accustomed to following certain procedures for QC and QA during OPC based concrete production, it will be an important educational step to change mindsets regarding management of the consistent quality and uniformity of incoming raw materials and output products. Technical operators must understand the strong dependence of product quality on the entire production processes, as there is no clinkerisation process as the "gate-keeper" of product quality.

4) Performance of geopolymer concrete in long term: The main issue in establishing a standard for performance assessment of geopolymer concrete is the acceptance of the accelerated testing methods and data evaluation processes. Most of the accelerated methods to assess durability are mainly designed for OPC based materials, with implicit assumptions regarding binder and pore solution chemistry, and are not always suitable for alternative materials such as geopolymers. There is often a conflict between the desire to innovate and develop a large scale project built with new materials, and the need for prior certification for new materials to realise a large scale project. In some jurisdictions (e.g. Japan, Austria), governments or authorities can provide special permits enabling practitioners to demonstrate long term behaviour of materials. However, in many other areas, this is a very challenging step.

5) Standardisation: In many markets, without the existence of specific standards and certification, new cement or concrete products may face great obstacles to market entry. To draft a new cement standard is not an easy process, as final consensus must be reached by the majority of the stakeholders who are participating in the standardisation committee. These stakeholders include industrial manufacturers,

trade associations (industry), professional institutions, government, consumer bodies, academia, education bodies, customers, and certification bodies. These various groups are interested not only in the use of standards to guarantee the quality and performance of their products or services, and to increase the safety of products and foster the protection of environment and health, but also to improve the competitiveness of their business through ensuring that their own systems comply with all legal obligations. As soon as a business advantage can be delivered by the suppliers to the customers, technical barriers to achieving final consensus will be readily removed. Thus, it is essential that the participants in this process are able to see the potential commercial (as well as environmental) benefits of geopolymer technology.

6) Acceptance from the customers: To win the acceptance of customers, sufficient convincing facts comparing an alternative material to OPC must be presented. These facts can either be opportunities or threats, such as economic benefits, better performance (e.g. strength, durability), or environmental competitiveness (e.g. green labelling, LEED credits). Education efforts can be focused on local councils, government authorities, corporations, project developers and architects, to highlight CO_2 emissions benefits and alleviate concerns or potential misconceptions held by the market stakeholders. Successful product education builds confidence in product performance, and in turn, creates project and technology advocates who further raise awareness within the specifier/user community. It is increasingly seen in the market that an additional "green advantage" for the end user can be the key element in achieving product differentiation.

DISCUSSIONS

It is noted that not every commercial endeavour related to geopolymer concrete has been with market success, and there are known complications related to water sensitivity, curing conditions and workability which are more challenging in the application of geopolymer concrete than for Portland cement concretes. However, there is a growing body of evidence which speaks in favour of the usability, durability and marketability of geopolymer concrete under service conditions in civil infrastructure applications. Moreover, there have been at least pilot-scale or demonstration projects in each of the areas discussed here, and each provides scope for future development and potentially profitable advances in science and technology.

Increasing efforts have been committed by leading practitioners from both academia and industry, to demonstrate the suitability of using geopolymer concrete in various applications, and to validate the long-term performance of this concretes. Customers in different market areas are becoming more and more aware of technical progress in the development of non-Portland binder systems, and geopolymer materials are ideally positioned to take advantage of this awareness. Although there are still great challenges facing geopolymer producers, concerted commercialisation efforts in parallel with ground-breaking research will be the only path forward to reach the final goal of large-scale deployment of this technology. Fundamental research should be targeted at improvement of the application and performance properties of geopolymer concrete, including development of chemical admixtures and analysis of durability, and remains pivotal to ongoing technical and commercial progress.

It has been recognised that innovative and non-conventional technology is difficult to transfer to practice, as existing standards do not allow for new technology, and new standards do not yet exist [48]. In the case of geopolymer concrete, it does not conform to most national and international cement standards, as they are mainly inherently based on the composition, chemistry and hydration products of OPC or OPC-blended cement. Existing cement standards therefore tend to rule out non-traditional binders and its products.

CONCLUSIONS

The increasing demand for environmental friendly and sustainable construction materials has necessitated the identification of alternative materials for OPC. In this regard, geopolymer binder, involving the use of various industrial wastes and by-products, has the potential to be considered as a promising alternative to OPC in various applications.

The main reasons for the lack of industrial application of geopolymer materials, to date, have been identified as: (a) Vested interests and established practices in the construction materials industry; (b) The huge technological gap between laboratory and industrial scale concrete in terms of the handling of powders and wet concrete, and the engineering behaviour of wet and hardened concrete; (c) A lack of industrial and commercial experience of many researchers; (d) A lack of understanding of supply chain dynamics and control; (e) Limited experience of a small selection of source materials, instead of extensive experience of a wide variety of source materials used under different operating conditions in different climates and countries.

A more rigorous approach to environmental assessment must be applied if claims of sustainability are to be justified, including careful assessment of the currency and accuracy of the data used as inputs into life-cycle studies. The preference of many customers is to make their first use of geopolymer concretes in lower-risk applications; particularly, projects which have flexible timelines, are readily accessible, and where the consequences of a material falling short of defined performance targets are limited. Progression to the use of a new material in higher-risk applications then requires the engagement of regulatory authorities, engineers and specifiers. These parties typically prefer to take a step-wise approach towards the development of standards and commercial adoption.

REFERENCES

1. Provis JL, van Deventer JSJ 2014 Alkali-activated Materials: State-of-the-art Report Springer Dordrecht, the Netherlands Rilem TC 224-AAM.
2. Duxson, P., Provis, J.L., Lukey, G.C., Separovic, F., van Deventer, J.S.J.: 29 Si NMR study ofstructural ordering in aluminosilicate geopolymer gels. Langmuir 21 (7), 3028–3036 (2005)
3. Provis, J.L., Lukey, G.C., van Deventer, J.S.J.: Do geopolymers actually contain nanocrystallinezeolites? – A reexamination of existing results. Chem. Mater. 17 (12), 3075–3085 (2005)
4. Duxson, P., Fernández-Jiménez, A., Provis, J.L., Lukey, G.C., Palomo, A., van Deventer,J.S.J.: Geopolymer technology: the current state of the art. J. Mater. Sci. 42 (9), 2917–2933(2007)
5. Glukhovsky, V.D.: Ancient, modern and future concretes. In: Krivenko, P.V., (ed.) Proceedingsof the First International Conference on Alkaline Cements and Concretes, Kiev, Ukraine. Vol.1, pp. 1–9. VIPOL Stock Company (1994)
6. Davidovits, J.: Geopolymers – inorganic polymeric new materials. J. Therm. Anal. 37 (8),1633–1656 (1991)
7. Provis, J.L., Lukey, G.C., van Deventer, J.S.J.: Do geopolymers actually contain nanocrystallinezeolites? – A reexamination of existing results. Chem. Mater. 17 (12), 3075–3085 (2005)
8. Fernández-Jiménez, A., Monzó, M., Vicent, M., Barba, A., Palomo, A.: Alkaline activation ofmetakaolin–fl y ash mixtures: obtain of zeoceramics and zeocements. Micropor. Mesopor.Mater. 108 (1–3), 41–49 (2008)
9. K. Srinivasan and A. Sivakumar, “Geopolymer Binders: A Need for Future ConcreteConstruction,” ISRN Polymer Science, vol. 2013, Article ID 509185, 8 pages, 2013]
10. Davidovits, J.: Geopolymer Chemistry and Applications. InstitutGéopolymère, Saint-Quentin (2008)
11. D.M.J. Sumajouw, B.V. Rangan, Low-calcium fly ash-based geopolymer concrete: Reinforced beams and columns. Research Report GC 3, Curtin, University of Technology, Pearth, Australia, 2006.
12. T.S. Ng, A. Amin, S.J. Foster, The behaviour of steel-fibre-reinforced geopolymer concrete beams in shear, Mag. Concr. Res. 65 (5) (2013) 308–318.
13. J.K. Dattatreya, N.P. Rajamane, D. Sabitha, P.S. Ambily, M.C. Nataraja, Flexural behaviour of reinforced geopolymer concrete beams, Int. J. Civil Struct. Eng. 2 (1) (2011) 138.
14. M. Rahman, P. Sarker, Geopolymer concrete columns under combined axial load and biaxial bending, Institute of Australia, 2011.

15. M. Rajendran, N. Soundarapandian, An experimental investigation on the flexural behavior of geopolymer ferrocement slabs, J. Eng. Technol. 3 (2) (2013).
16. S. Nagan, R. Mohana, Behaviour of geopolymer ferrocement slabs subjected to impact, Iranian J. Sci. Technol. Trans. Civil Eng. 38 (C1+) (2014) 223.
17. Z. Abdollahnejad , F. Pacheco-Torgal, T. Félix, W. Tahri, J. Barroso Aguiar, Mix design, properties and cost analysis of fly ash-based geopolymer foam, Constr. Build. Mater 80 (2015) 18–30.
18. R.T.T. Fongang, J. Pemndje, P.N. Lemougna, U.C. Melo, C.P. Nanseu, B. Nait-Ali, E. Kamseu, C. Leonelli, Cleaner production of the lightweight insulating composites: Microstructure, pore network and thermal conductivity, Energy Build. 107 (2015) 113–122.
19. Z.N.M. NGouloure, B. Nait-Ali, S. Zekeng, E. Kamseu, U.C. Melo, D. Smith, C. Leonelli, Recycled natural wastes in metakaolin based porous geopolymers for insulating applications, J. Build. Eng. 3 (2015) 58–69.
20. R.M. Novais, L.H. Buruberri, G. Ascensao, M.P. Seabra, J.A. Labrincha, Porous biomass fly ash-based geopolymers with tailored thermal conductivity, J. Cleaner Production 119 (2016) 99-107.
21. Z. Zhang, J.L. Provis, A. Reid, H. Wanga, Mechanical, thermal insulation, thermal resistance and acoustic absorption properties of geopolymer foam concrete, Cem .Concr. Compos. 62 (2015) 97–105.
22. L. Li, S. Wang, Z. Zhu, Geopolymeric adsorbents from fly ash for dye removal from aqueous solution, J. Colloid. Interface. Sci. 300 (2006) 52–59.
23. Y. Ge, X-m. Cui, Y. Kong, Z. Li, Y. He, Q. Zhou, Porous geopolymeric spheres for removal of Cu(II) from aqueous solution: Synthesis and evaluation, J. Hazardous Mater. 283 (2015) 244–251.
24. Shi, C., Krivenko, P.V., Roy, D.M.: Alkali-Activated Cements and Concretes. Taylor & Francis, Abingdon (2006)
25. Krivenko, P.V., Kovalchuk, G.Y.: Heat-resistant fl y ash based geocements. In: Lukey, G.C. (ed.) Geopolymers 2002. Turn Potential into Profi t, Melbourne, Australia. CD-ROM Proceedings. Siloxo Pty. Ltd. (2002)
26. Krivenko, P.V., Kovalchuk, G.Y.: Directed synthesis of alkaline aluminosilicate minerals in a geocement matrix. J. Mater. Sci. 42 (9), 2944–2952 (2007)
27. J. Temuujin, W. Rickard, M. Lee, A. van Riessen, Preparation and thermal properties of fire resistant metakaolin-based geopolymer-type coatings, J. Non-Crystal Sol. 357 (2011) 1399–1404.
28. Z. Zhang, K-t. Wang, B. Mo, X. Li, X-m. Cui, Preparation and characterization of a reflective and heat insulative coating based on geopolymers, Energy Build. 87 (2015) 220–225.
29. Z. Zhang, X. Yao, H. Wang, Potential application of geopolymers as protection coatings for marine concrete III. Field experiment, Appl. Clay Sci. 67 (2012) 57–60.

30. D. Wiyono, Antoni, D. Hardjito, Improving the durability of pozzolan concrete using alkaline solution and geopolymer coating, The 5th International Conference of Euro Asia Civil Engineering Forum (EACEF-5), Procedia Eng. 125 (2015) 747 – 753.
31. L.Y.D. Kong, G.J. Sanjayan, Damage behavior of geopolymer composites exposed to elevated temperatures, Cem. Concr. Compos. 30 (2008) 986–991.
32. J. Davidovits, Geopolymers: inorganic polymeric new materials, J. Therm. Anal. 37 (1991) 1633–1656.
33. J.L. Bell, P.E. Driemeyer, W.M. Kriven, Formation of Ceramics from Metakaolin-Based Geopolymers. Part II: K-Based Geopolymer, J. Am. Ceram. Soc. 92 (2009) 607-615.
34. Zhao, R., Sanjayan, J.G.: Geopolymer and Portland cement concretes in simulated fi re. Mag. Concr. Res. 63 (3), 163–173 (2011)
35. Kovalchuk, G., Krivenko, P.V.: Producing fi re- and heat-resistant geopolymers. In: Provis, J.L., van Deventer, J.S.J. (eds.) Geopolymers: Structures, Processing, Properties and Industrial Applications, pp. 229–268. Woodhead, Cambridge (2009)
36. Comrie, D.C., Kriven, W.M.: Composite cold ceramic geopolymer in a refractory application. Ceram. Trans. 153 , 211–225 (2003)
37. Fullston, D., Sagoe-Crentsil, K.: Small footprint aluminosilicate matrix – refractory hybrid materials. J. Aust. Ceram. Soc. 45 (2), 69–74 (2009)
38. Medri, V., Fabbri, S., Ruffini, A., Dedecek, J., Vaccari, A.: SiC-based refractory paints prepared with alkali aluminosilicate binders. J. Eur. Ceram. Soc. 31 (12), 2155–2165 (2011)
39. Buchwald, A., Oesterheld, R., Hilbig, H.: Incorporation of aluminate into silicate gels and its effect on the foamability and water resistance. J. Am. Ceram. Soc. 93 (10), 3370–3376 (2010)
40. Fletcher, R.A., MacKenzie, K.J.D., Nicholson, C.L., Shimada, S.: The composition range of aluminosilicategeopolymers. J. Eur. Ceram. Soc. 25 (9), 1471–1477 (2005)
41. Sukhanevich, M.V., Guzii, S.G.: The effect of technological factors on properties of alkali aluminosilicate systems used for preparation of fi reproof coatings. Refract. Ind. Ceram. 45 (3), 217–219 (2004)
42. Temuujin, J., Minjigmaa, A., Rickard, W., Lee, M., Williams, I., van Riessen, A.: Fly ash based geopolymer thin coatings on metal substrates and its thermal evaluation. J. Hazard. Mater. 180 (1–3), 748–752 (2010)
43. Uehara, M.: New concrete with low environmental load using the geopolymer method. Quart. Rep. RTRI 51 (1), 1–7 (2010)
44. Małolepszy, J., Deja, J., Brylicki, W.: Industrial application of slag alkaline concretes. In: Krivenko, P.V. (ed.) Proceedings of the First International Conference on Alkaline Cements and Concretes, Kiev, Ukraine. Vol. 2, pp. 989–1001. VIPOL Stock Company (1994)

45. Deja, J., Brylicki, W., Małolepszy, J.: Anti-fi ltration screens based on alkali-activated slag binders. In: Ertl, Z. (ed.) Proceedings of the International Conference on Alkali Activated Materials – Research, Production and Utilization, Prague, Czech Republic, pp. 163–184. Českározvojováagentura (2007)
46. Fernández-Jiménez, A., Palomo, A., Revuelta, D.: Alkali activation of industrial by-products to develop new Earth-friendly cements. In: 11th International Conference on Non-conventional Materials And Technologies (NOCMAT 2009), Bath, UK. CD-ROM proceedings (2009)
47. Palomo, A., Fernández-Jiménez, A., López-Hombrados, C., Lleyda, J.L.: Railway sleepers made of alkali activated fl y ash concrete. Rev. Ing. Constr. 22 (2), 75–80 (2007)
48. Hooton, R.D.: Bridging the gap between research and standards. Cem. Concr. Res. 38 (2), 247–258 (2008)

"A study on influence of dilution of alkaline to binder rations on fresh and harden behaviour of Geopolymer mortar"

Vishwanath K Dalawai[1] & Prashanth V P[2]

[1] Deputy Manager, JSW Cement Ltd, Bangalore, Karnataka, India.
[2]Assistant Professor, Department of CT&M, SJCE, Mysore, Karnataka, India.

ABSTRACT

The Geo-polymer mortar (GPM) is proven his state of art for its strength, durability and sustainability [2 &3]; strength of GPM is a function of Alkaline to binder ratio, and which has adverse effect on consistence properties of mortar. Early research proven the art of sundry curing GPM, with a combined binder fly-ash and GGBFS [11]. The fresh properties of GPM can be improved with the dilution of alkaline to binder ratio (Free Moisture) up to limit with refer to flow table test, Consistency of GM increases with increase in the water-to-alkaline binder ratio, but in the mean way which affect inversely with compressive strength[ ]. The present investigation of pH in alkaline solution evident the degree of dilution of solution may not alter the mechanism of Geo-polymerization with addition of water. Commercial available Sodium silicate solution as alkali and 4 molar sodium hydroxide solutions were used as alkaline activators. Activated alkaline solution to binder ratio of 0.5 - 0.8 for Rich mortar (1:3) and lean mortar (1:6) by mass was maintained constant for the study of dilution and bond strength properties of GPM. FA and GGBFS based 1:3 and 1:6 GPM offers early strength of order 5-12 MPa for three days Sun-dry curing regime. GPM with alkaline to binder ratio 0.23 to the dilution up to 0.8 may offers good shear bond strength of 0.52N/mm^2 & 0.31 N/mm^2 for 10mm - 5mm masonry joint.

Keywords: Constancy, pH Dilution, Bond strength, Triplet, Constancy, Sun-dry curing.

1 INTRODUCTION

The geopolymer is taken a much attention from present decades, due to environmental concern related to the production of cement in terms of energy consumption and carbon foot print. One such alternative material for the cement is the use of alkali-activated binder using industrial by-products containing silicate materials. The most common industrial by-products used as binder materials are fly ash and blast furnace slag. Slag has been used as cement replacement material due to the latent hydraulic properties, while fly ash has been used as pozzolanic material to enhance physical, chemical and mechanical properties of mortars. The utilization of large proportion of by-products would contribute to the elimination of an environmental problem and to the development of potentially new high-performance material. Recent research has shown that it is possible to use fly ash or slag as a sole binder in mortar by activating them with an alkali component. The activation of material containing mostly silicate and aluminates by a highly alkaline solution will form an inorganic binder through a polymerization process in 1979 [1&3].

The current research is evident that GPM can be cured in sun-dry condition with proportionate combine binder FA&GGBFS [11]. Alkaline to binder ration place significant role in predicting the properties of GPM. To achieve a good consistence in GPM, increasing the alkaline binder ratio, there is significant effect setting of mortar. In this study attempt is made to enhance the consistency of GPM, with dilution of alkaline solution and its impact on Geopolymerization and some basic harden properties are studied.

2. MATERIAL AND METHODS

2.1. Fly ash and GGBS

In the present investigation Class F fly ash and GGBS are considered as binder. The physical characteristics are reported in Table-1.

Particulars	Fly ash	GGBS
Residue on 45µ sieve	24.4%	2.9%
Specific gravity	2.2	2.8
Fineness (Blaine's air permeability)	252.30m^2/kg	521.7m^2/kg

Table 1: Physical Properties of Binders

2.2. Aggregate

Locally available river sand is chosen as filler, which confirm the requirements Indian standards.

2.3 Alkaline solution

The locally available sodium silicate and sodium hydroxide solution are used in the present investigation as alkaline solution. The sodium hydroxide is in flakes and pellet with about 98% purity. These pellets were mixed with distilled water to obtain the sodium hydroxide solution of required molarity. In the present study, 4M (4*40g=160g) NaOH solution is considered for investigations. The commercial grade of sodium silicate which has purity of 78% and contains 27% of water is used in the present investigation [7].

2.4. Curing of the specimens

The GPM specimens are cured in sun-dry for atmospheric humid factor and varying temperature. The sun-dry curing specimens were covered with a thick polythene sheet in order to reduce the moisture cracks and conventional impression curing is adopted for conventional cement mortar.

3. RESULTS AND DISCUSSION

3.1 Influence of addition of water on pH value of combined alkaline solution.

The defining properties for GPM are the alkaline to binder ratio. In the view of enhancing the workability for required strength, an attempt has been made to replace alkaline to binder ratio with water to binder ratio in the mix. The effect of addition of water on the alkalinity of solution is evident thorough pH observation of combined solution of NaOH and Na_2Sio_3.

Alkaline solution (ml)	Water (ml)	pH values 1St Day	pH values 2nd Day	pH values 3rd Day
100	00	13.7	13.7	13.7
90	10	13.62	13.62	13.62
80	20	13.58	13.58	13.58
70	30	13.52	13.52	13.52
60	40	13.48	13.50	13.50
50	50	13.42	13.42	13.44
40	60	13.34	13.32	13.36
30	70	13.24	13.24	13.24
20	80	13.12	13.14	13.14
10	90	12.88	12.88	12.90
00	100	7.82	7.94	7.98

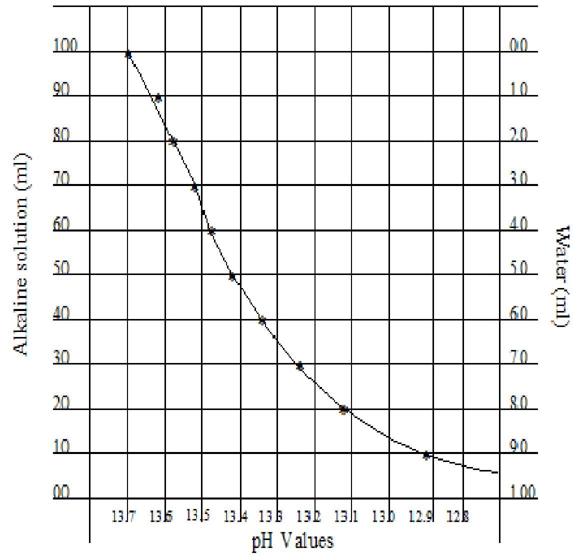


Fig. 1. Graph showing the pH values of the alkaline solution with respective addition of water.

Table-2: Ph Value of Alkaline Solution with Respective Addition of Water

The results clearly shows that the alkalinity of combined solution does not vary much with the addition of water and there is no significant change in the pH of alkaline solution for the observation of 1, 2 and 3 days in laboratory condition .Hence it can be said that there is no change in the alkalinity of geopolymer solution for continues incremental addition of water**.**

Cement mortar						**Geopolymer mortar**					
Mix No	**Mix Proportions**	**Alkali/ Binder Ratio**	**Flow Values (mm)**	**Compressive Strength MPa**		**Mix No**	**Mix Proportions**	**W/C Ratio**	**Flow Values (mm)**	**Compressive Strength MPa**	
				3days	**7days**					**3days**	**7days**
S1	1:3	0.64	195	10.20	12.44	N1	1:3	0.72	195	13.2	19.59
S2	1:3	0.68	200	9.38	11.15	N2	1:3	0.8	200	11.28	17.95
S3	1:3	0.72	210	6.44	8.57	N3	1:3	0.88	210	9.24	16.32
M4	1:6	1.13	195	3.67	6.32	P4	1:6	1. 3	175	7.89	12.24
M5	1:6	1.23	200	2.86	5.71	P5	1:6	1.39	200	7.02	11.28
M6	1:6	1.3	210	2.04	4.49	P6	1:6	1.5	210	6.59	10.2

Table-3: flow and compressive strength for different mix proportions

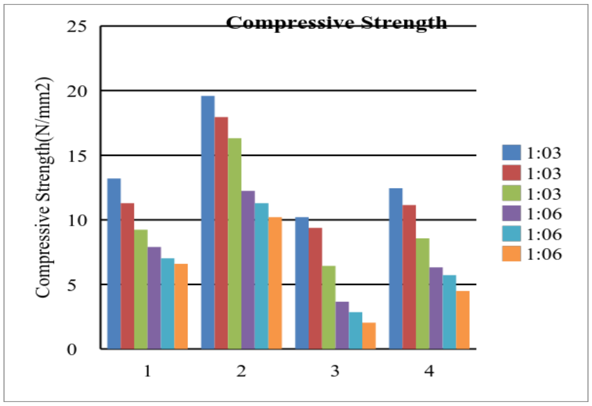


Fig. 2. Compressive strength v/s Mix proportions

3.2. Influence of dilution of Alkaline to binder ratio on the properties of GPM.

As the geopolymer consists of binders and alkali solution, it is necessary to optimize the solution content required for the matrix. Therefore the solution content required for the different alkali solution to binder ratios were done for the mixes considered for the study i.e., 1:3 and 1:6. Different ratios have been considered starting from 0.36 to 0.72. The optimum values from the ratios will result in required flow. Primarily few trial mixes were made to fix up the alkali solution to binder ratio using flow table test. Three trials for each mix have been made and tested. The average of all the three trials per each mix has been tabulated in table-4.

GPM offers good early strength and it is evident that strength of GPM is based on the percentage of alkaline solution. hence for further work, min alkaline to binder for good flow values are chosen as from TABLE VII and have been kept constant and increasing the amount of water on basis of the flow value or workability in the study. According to IS 2250-1981, the mortar flow should be around 100% to 110% i.e., 200 to 210mm flow depending upon the purpose of mortar.

Sl No	Mix Proportions	Alkaline/Binder Ratio	Flow Values (mm)
1	1:3	0.4	Nil
2	1:3	0.5	157.5
4	1:6	0.8	Nil
5	1:6	1	Nil

TABLE-4: Alkaline binder Ratio for Mortar

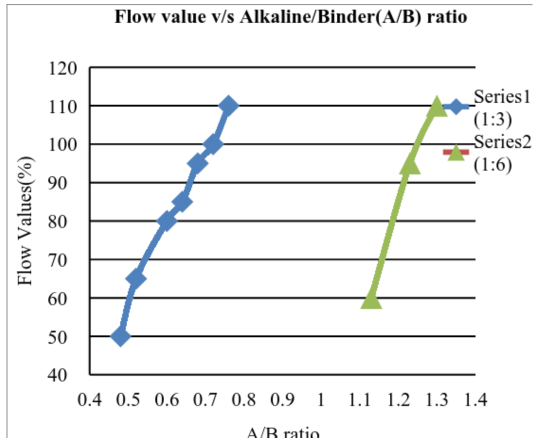


Fig. 3. Variation of Flow values (%) v/s Alkaline/Binder (A/B) ratio

The trend (fig.3) between the flow values in % and the Alkaline/Binder (A/B) ratio fallows an approximately linear relationship; this relationship is more convenient to use the Alkaline/Binder ratio curve for interpolation.

	Added W/A ratio	Binder (kg)		Alkaline solution (kg)		Sand (kg)	Added water (kg)		Dry Density (kg/m³)	Av. Compressive strength (MPa) , for day			
										Sun-dry curing		Water curing	
		Fly ash	GGBS	Na_2SiO_3	NaoH					3	7	3	7
M1	0.375	472.5	52.5	105	105	1575	78.75	75	2111.9	12.24	13.59	8.97	10.74
M2	0.437	472.5	52.5	105	105	1575	91.77	85	2088.8	10.33	11.97	7.75	9.39
M3	0.52	472.5	52.5	105	105	1575	109.2	110	2110.0	8.84	9.24	5.3	5.57

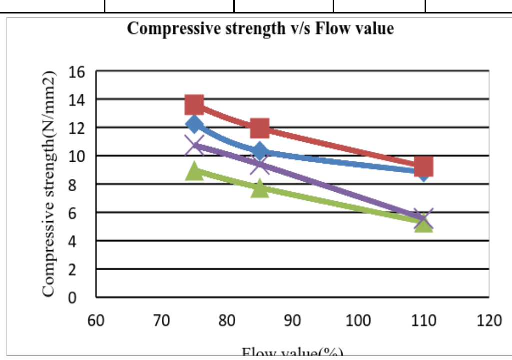


Fig. 4. Compressive strength v/s Flow value (%)

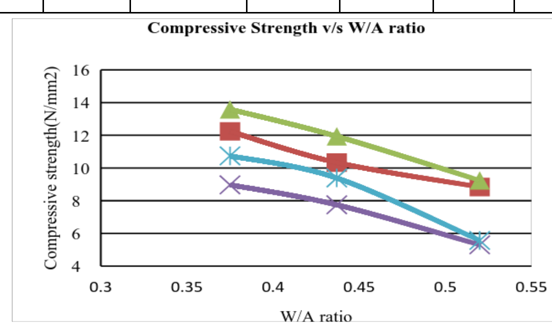


Fig. 5. Compressive strength v/s Water/Alkaline (W/A) ratio

Table- 5. Effect of variation of water to alkaline ratio (w/a) for a/b ratio 0.4 of 1:3 mortar/cu-m.

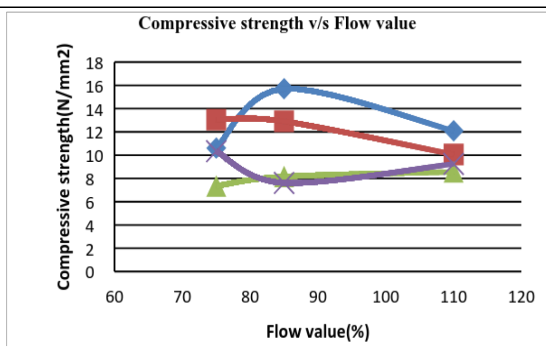
The strength of mortar primarily depends upon the strength of the binder paste. The strength of paste increases with binder content and reverse with voids and alkaline content. The strength of mortar is only depends upon water/alkaline ratio, provided the mix is workable in GPM. The relation between the water/alkaline ratio and the strength is shown in fig 4 and 5. It is observed that lower water/alkaline ratio achieves higher strength, whereas comparatively higher water/alkaline ratio give lower strength.

- **Relationship between the compressive Strength v/s Flow values**

The relation between the strength and the flow values in % is shown in fig 9 and 10. It is evident that increase in the flow value decreases the strength. When the flow value is low, the workability is low, and it gives the higher strength.

Mix No- S1	**Added W/A ratio**	**Binder (kg)**		**Alkaline solution (kg)**		**Sand (kg)**	**Added water(kg)**	**Flow table value (%)**	**Dry Density (kg/m3)**	**Avg Compressive strength (MPa)**			
										Sun-dry curing		**Water curing**	
		FA	**GGBS**	**Na_2Sio_3**	**NaoH**					3 Days	7 Days	3 Days	7 Days
,M1	0.18	472.5	52.5	131.25	131.25	1575	47.25	75	2120	10.61	13.05	7.35	10.34
M2	0.2	472.5	52.5	131.25	131.25	1575	52.5	85	2080	15.71	12.91	8.16	7.61
M3	0.22	472.5	52.5	131.25	131.25	1575	57.75	110	2100	12.10	10.06	8.56	9.25

Table-6. Effect of variation of water to alkaline ratio (w/a) for a/b ratio 0.5 of 1:3 mortar. per cu-m



Compressive strength v/s Flow value (%)

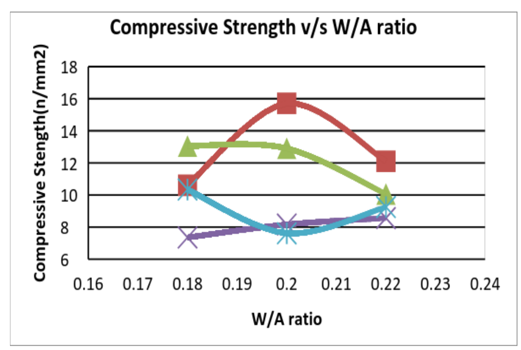


Fig. 6. Compressive strength v/s Water/Alkaline (W/A) ratio

	Added W/A ratio	**Binder (kg)**		**Alkaline solution (kg)**		**Sand (kg)**	**Added water (kg)**	**Flow table value (%)**	**Dry Density (kg/m^3)**	**Avg Compressive strength (MPa)**	
		FA	**GGBS**	**Na_2Sio_3**	**NaoH**					**Sun-dry curing**	**Water curing**

Mix No										3 Days	7 Days	3 Days	7 Days
S2,N1	0.473	270	30	120	120	1800	113.52	180	2008.5	2.85	4.11	4.76	1.27
S2,N2	0.509	270	30	120	120	1800	122.16	195	2048.5	2.31	3.80	4.48	1.15
S2,N3	0.545	270	30	120	120	1800	130.8	210	2010.9	2.04	3.39	4.21	1.06

Table-7. Effect of variation of water to alkaline ratio (w/a) for a/b ratio 0.8 of 1:6 mortar.

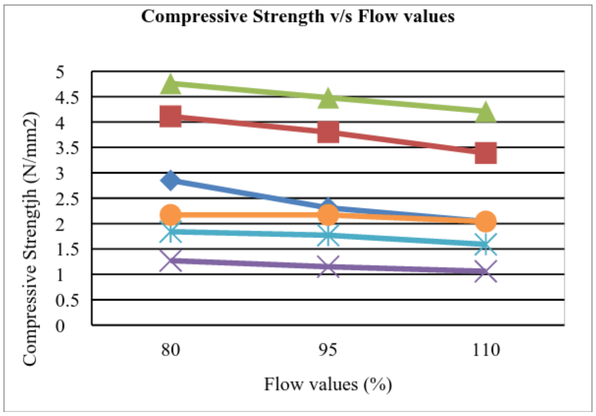


Fig. 8. Compressive strength v/s Flow value (%)

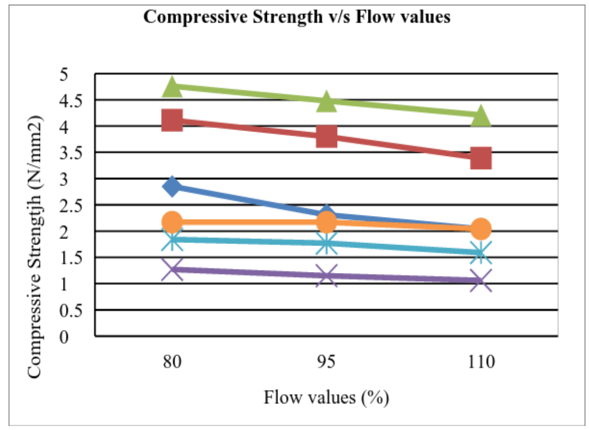


Fig. 9. Compressive strength

3.4. Shear Bond Strength of Geopolymer Mortar

The geopolymer mortar bond strength of masonry specimen is determined by testing masonry triplet under shear. The main objective is to evaluate the strength of mortar mixes with varying proportions by determining the shear strength of triplets and comparing it with the conventional mortar mixes.

Table-8. Shear strength of solid concrete blocks

Sl No	**Direction of the plane**	**Thickness of the mortar joint(mm)**	**Failure load (N)**	**Shear strength (N/mm^2)**
1	Vertical	10	28000	0.52
2	Horizontal	5	35000	0.31

Fig. 10. Block masonry (400*190*150mm, 1:6 mortar mix)

4. CONCLUSION

The experimental work on the consistent factors of GPM is evident for the following observations

- Alkalinity of the solution doesn't change with dilution with free moisture and may not alter the chemistry of polymerization solution and may not alter the Geoploymer mechanism in GPM.
- Utilization of GGBS as binder to a certain extent (i.e.5-10%) improves the setting time and compressive strength of the geopolymer mortar as compared to conventional mortar. And also added the word self-curing for sundry curing application.
- The results is evident that using fly ash along with GGBS as base material and alkaline solution dilution of free moisture, it is possible to produce mortar of compressive strengths of the order of 5-15MPa. And offers an early strength (about 5-7 MPa in 3 days of sun dry curing) as compared with conventional mortars.
- Bond strength of the GPM (of thickness 5mm and 10mm) is found to be 0.31N/mm^2 for horizontal plane and 0.52N/mm^2 for vertical plane than the conventional cement mortar.

REFERENCE

[1]. Cheng, T. W. and J. P. Chiu. "Fire-resistant Geopolymer Produced by Granulated Blast Furnace Slag." Minerals Engineering 16(3): 205-210, 2003.

[2]. F.Rendelland R. Jauberthie, "The deterioration of mortar in supphate environment". Cement and concrete Research pp. 321-327, 1999.

[3]. J. Davidovits, "Properties of Geopolymer Cements". Procedings of the first international conference on alkaline cements and concretees. Vol. 1 SRIBM, Kiev, Ukraine, pp. 131-149. 1994.

[4]. Jae Eun Oh , Paulo J.M. Monteiro , Ssang Sun Jun , Sejin Choi , Simon M. Clark, "The evolution of strength and crystalline phases for alkali-activated ground blast furnace slag and fly ash-based geopolymers" Department of Civil and Environmental Engineering, University of California, Berkeley, CA 94720, USA, 2009.

[5]. Jumrat,S. Chatveera,B. and Rattanadecho,P. "Dielectric properties and temperature profile of fly ash-based geopolymer mortar", International Communications in Heat and Mass Transfer ,2010 Elsevier.

[6]. K.K.Deevasan, (2008) A Study on -"Geopolymer concrete using Industrial effluent", M.Tech Thesis (Department of Civil Engineering; BMS College of Engineering), Submitted to Visvesvaraya Technological University –Karnataka

[7]. M. D. Cohen and B. Mather, "Sulfate attack on concrete". Research needs ACI materials Journal, pp. 62-69, 1991.

[8]. Mohammed Saleh. (2007). "A Study on Geopolymer Concrete incorporating Flyash", M.Tech Thesis (Department Of Civil Engineering; BMS College of Engineering), Submitted to Visvesvaraya Technological University –Karnataka.

[9]. Mohammed,M. Kamarudin,H.I, Niza,K. and Zarina,Y. "Review on fly ash-based geopolymer concrete without Portland Cement", Journal of Engineering and Technology Research Vol. 3(1), pp. 1-4, January 2011.

[10]. Palomo, M.W. Grutzeck, M.T. Blanco,"Alkaline activated fly ashes cement for the future". Cement and concrete research, pp. 1323-1329, 29. 1991

[11]. Prashanth V P, R.V. Ranganath and M.S. Sudarshan "Sun cured alkali activated concrete-Some basic properties", International Conference on "world of concrete India", October 24-26, Hyderabad – 2013.

[12]. Wallah, S. E., & Rangan, B. V. Low-Calcium Fly Ash-Based Geopolymer Concrete: Long-Term Properties, Research Report GC 2. Perth: Faculty of Engineering Curtin University of Technology. 2006.

Photo Gallery


OPPO F11


Geopolymer Concrete Applications:
Challenges and Opportunities
(Smart Techniques and Solutions for Ecofriendly Sustainable Constructions)