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SOLID WASTE MANAGEMENT BY GEOPOLYMERIZATION: CONSOLIDATION AND VALUE ADDITION OF ALUMINIUM INDUSTRY REJECTS

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About the presenter

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Work experience: 23 years experience at JNARDDC as Scientist in various domains viz. Industrial Waste Processing and Product development, Geopolymer, Rapid Analytical Methods and Planar Chromatography

R&D experience: Applied research experience on material recycling, process and product development from byproducts of ferrous and non-ferrous industries.

Wet delamination of Multi-Layer Packaging rejects (MLP) & Single use Paper Cup (SUPC) for recovering paper, aluminium and plastics (PE&PP)

Content

Introduction

An inevitable consequence of industrial progress is generation of reject. Therefore, efficient waste management is a matter of concern for balancing development and sustainability of environment.

Mining

Refining

Smelting

Aluminium industry represents both primary and secondary aluminium production and the overall upstream activities of metal production generates variety of solid by-products which are broadly classified into processed and unprocessed rejects.

In general, the rejects of aluminium industry origin are alumino-siliceous resources such as high silica and low alumina fractions, left unused and kept as future resource or used in landfills

Solid wastes of aluminium industry

Outlook on Process Leftover /Byproducts

Waste	Reject	Resource

Major rejects of aluminium industry are inorganic materials appear in the form of solid materials of various kind having differential chemical and mineralogical compositions containing aluminium, iron and silica as major components.

Material properties

Both primary and secondary production of aluminium are left with variety of solid rejects which are useful materials of productive applications.

They are useful as such and in processed forms.

The advantage of rejects from aluminium industry is that they posses innate material synergy among themselves and many reject materials of other industries such as steel, power, oil and biomass etc.

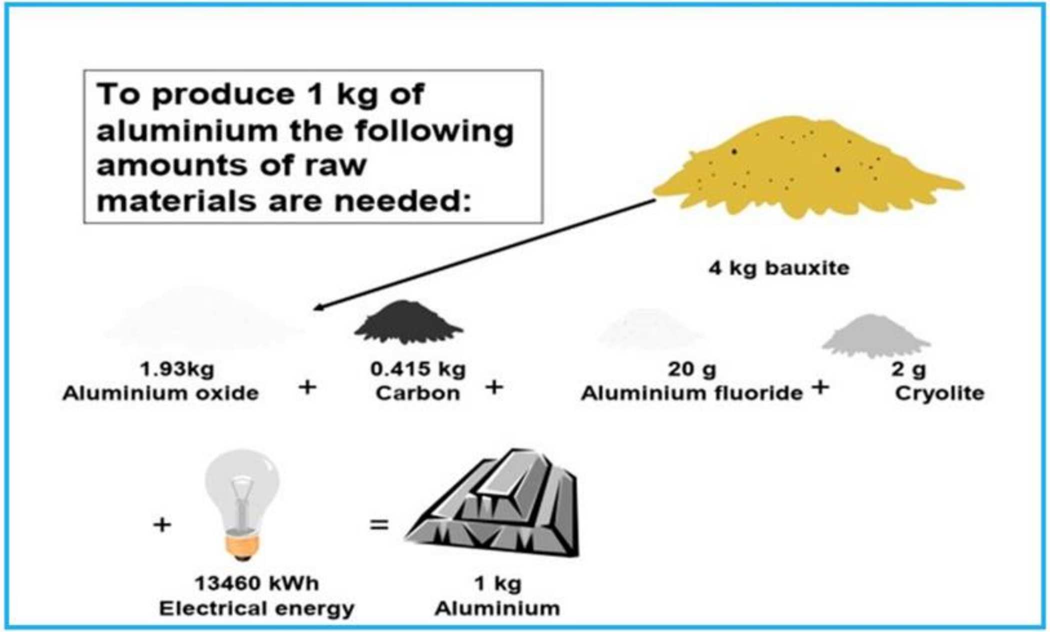
The details are discussed here as alternate resources for the production of different types of building materials based on a non-fired and chemical process route.

This presentation precisely highlights the potential of the processed and unprocessed solid rejects of aluminium industry origin as resources for making geopolymer products along with technical hints of value addition for commercial exploitation.

Material input and quantum of waste

Indirectly, quantum of solid waste represents extent of pollution and waste of resources

Raw material for production of 1 kg Aluminium



Solid Waste

Industrial solid waste

- Mining
- Processing
- Production
- Recycling

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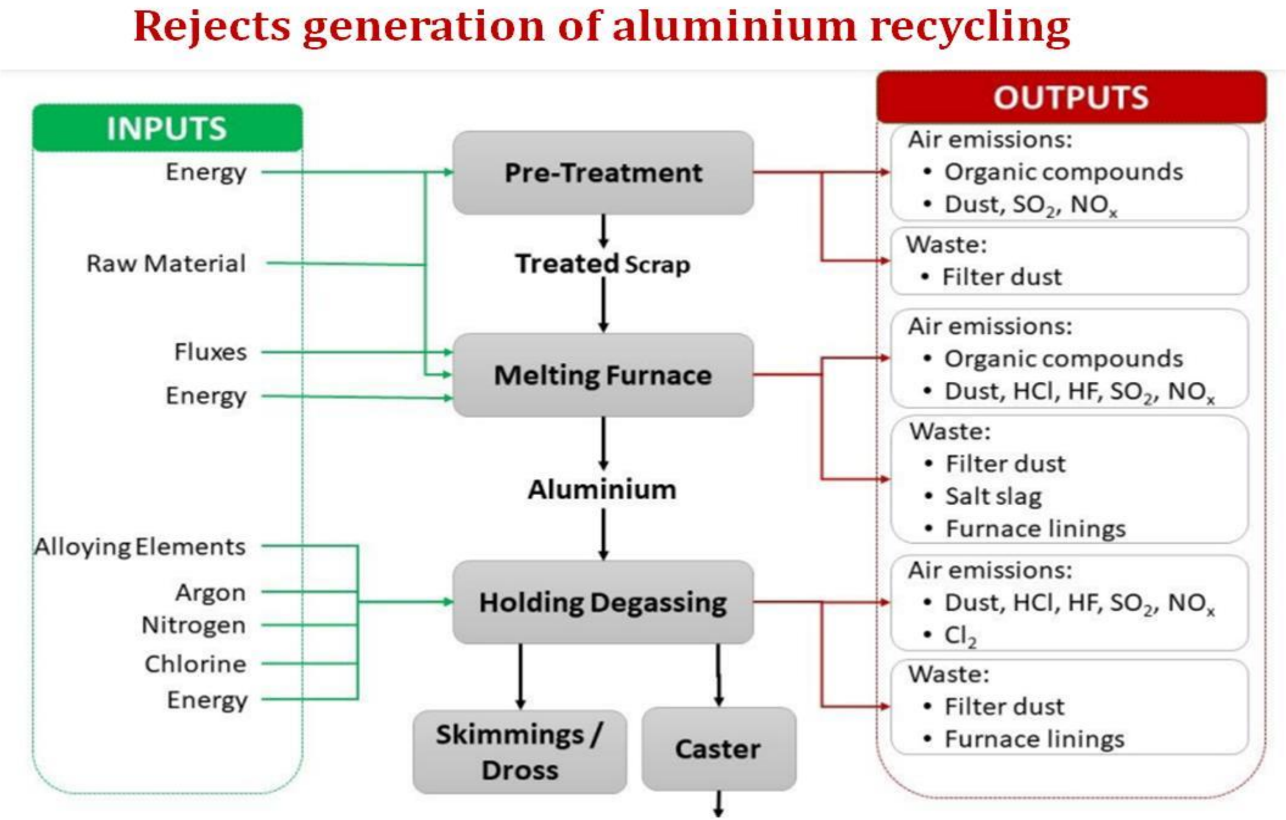
Waste generation of Al recycling

Secondary Aluminium



Aluminium quality is not impaired by recycling.

It can be repeatedly recycled and hence aluminium retains a high scrap value.

Almost 100% of the scrap arising from manufacturing of aluminium products is being recycled.

Unprocessed and processed rejects

Low-grade Bauxite (LB), Overburden Laterite (OBL) and Kaolinitic Khondalite (KK), Partially Lateritised Khondalite (PLK), Lithomargic clay known as Saprolite (SL) etc. are some of the major unprocessed resources largely associated and available at the bauxite mining site.

Processed rejects of aluminium production mainly represent the Red Mud (RM), Aluminium Dross (AD) and Spent Pot-lining Materials (SPL).

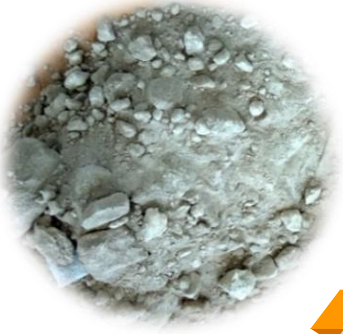
Major unprocessed solid rejects of primary aluminium industry

L

S

PLK

KK



Chemical composition of unprocessed rejects

Chemical characteristics

Composition %								
Sl	Reject material	Al_2O_3	Fe_2O_3	SiO_2	L.O.I	TiO_2	Na_2O	CaO
3	L	29.32	41.00	08.42	17.40	01.82	0.01	00.85
4	S	33.51	01.80	43.92	15.03	03.29	00.04	00.08
5	PLK	36.36	18.08	31.04	18.48	01.58	00.04	00.50
6	KK	36.72	19.80	20.65	16.25	01.82	00.07	ND

Average composition : Actual values vary in the range ±5% max.

RM: Red Mud; FA: Flay Ash; L : Laterite; S: Saprolite; PLK: Partially Lateritised Khondalite; KK : Kaolinitic Khondalite; SPL: Spent Pot Line

Source and Abundance

Aluminium dross, Bauxite residue (Red mud), Spent pot lining (SPL), Filter dusts, Salt slag and Furnace lining are major processed waste/rejects originated

Nature of waste	Generation
Red-mud	≈ 4.7 m.t/annum
Fly-ash (captive power plant)	≈ 7 m.t/annum
SPL	≈ 50,000 t/annum
Dross	≈ 4,000 t/annum

Secondary aluminium production is mostly unorganized and have no comprehensive data about reject generation and reuse and utilization

Largest processed solid reject

Red mud

2 ton Alumina

\+

1 ton Al

→

3 ton mud

Chemical composition of red mud

Component	Chemical composition (%)					
	1	2	3	4	5	6
Al_2O_3	17-19	17-19	19-20	17-20	18-22	18-21
Fe_2O_3	48-53	35-36	44-46	44-47	40-26	35-37
SiO_2	04-05	07-08	05-06	07-08	12-16	06-06
TiO_2	03-04	16-14	17-18	08-10	02-03	17-19
Na_2O	03-04	05-06	03-03	03-04	04-04	05-05
CaO	0.8-01	03-04	01-02	01-03	01-02	01-02
LOI	10-13	10-12	12-14	10-14	11-15	11-14

1-NALCO, Damanjodi; 2- HINDALCO Renukoot; 3- HINDALCO,Muri; 4- HINDALCO Belgaum; 5- MALCO, Mettur; 6-BALCO,Korba

Chemical composition of processed rejects

1^{st} cut SPL

Constituents	% Conc.
Al Metal	**15-20**
Fe_2O_3	0.96
Na_2O	**0.24**
TiO_2	0.92
SiO_2	**1.10**
CaO	**0.62**
Fluoride	< 0.1

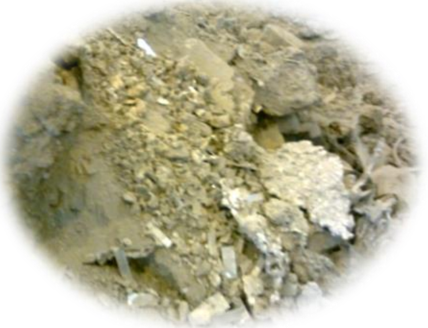
2^{nd} SPL cut

Constituents	% Conc.
SiO_2	**14-45**
Al_2O_3	**21-50**
Na_2O	**15 - 24**
K_2O	0.4-1.1
MgO	0.3-0.6
CaO	1.5-4.2
Fe_2O_3	2 - 15
TiO_2	0.4-1.4
P_2O_5	ND-0.2
C	1.3 - -4.5

Used Anode Butts

Sample	Fluoride (%)		Sodium (%)	
	Total	**Leachable**	**Total**	**Leachable**
Chip-off	50-54	3-4	**22-26**	**1-2**
Middle	< 1%	< 1%	< 1%	< 1%
Core	< 0.5	< 0.5	< 0.5	< 0.5

Aluminium Dross



Constituents	% Conc.
Al metal	**10-80**
Al_2O_3	**20-90**
SiO_2	**1-4**
Fe_2O_3	0.5-4
CaO	0.1-0.5
K_2O	0.8-1.5
Na_2O	**0.5-2**
Others	Traces

Resource augmentation

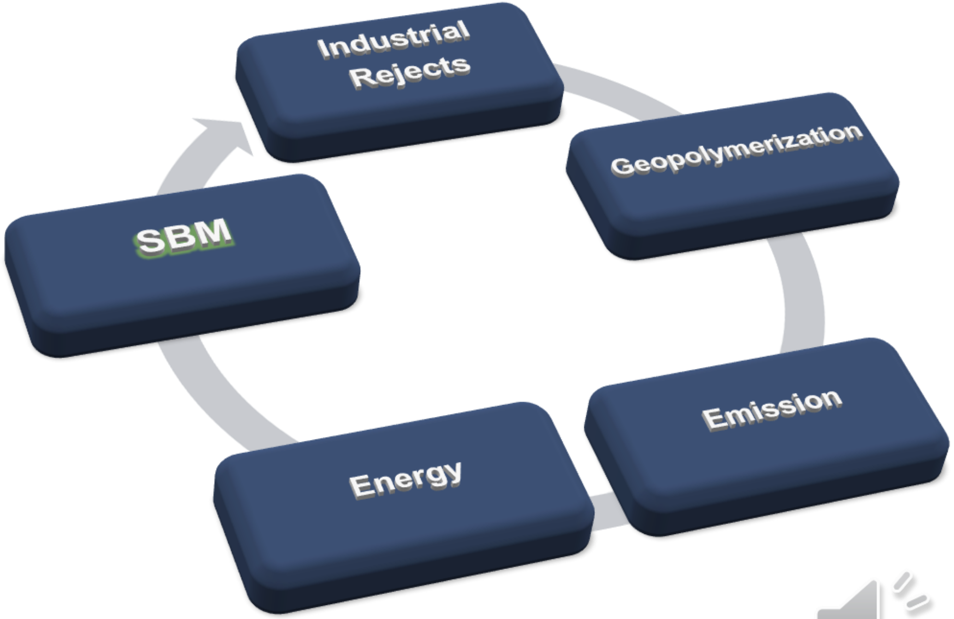
Significance

Aluminium industry rejects posses high mineral values and excellent properties suitable for making **Sustainable Building Materials (SBM)** useful for infrastructural and construction applications.

Sustainable construction refers to the adoption of building designs, construction methods and materials that are environmentally amenable.

Through Sustainable construction, we optimize the use of natural resources via recycling and reuse of materials so as to reduce our dependence on natural raw materials.

Sustainable utilization



Geopolymer

Geopolymers (GEOP) are amorphous alumino silicates which can be produced by the reaction between **silica** and **alumino silicates** in **alkaline medium** at ambient OR elevated temperature (25 – 100 ^{0}C).

The technology was first introduced by **Joseph Davidovits in 1978** and his work shows that its adoption could reduce the **CO_2 emission** caused due to cement industries. GEOP production process is **simple, energy efficient and eco-friendly,** it exhibits **excellent durability** and **good mechanical properties** and can replace **conventional materials** from **low tech** to **high tech applications.**

In general, **Every material is suitable for geopolymer production** which contains **silica** and **alumina** bearing phases

Geopolymerization : 2 basic steps

Dissolution of solid alumino-silicate oxides by alkali to produce reactive silica and alumina

Polycondensation process leading to formation of amorphous to semi-crystalline polymers

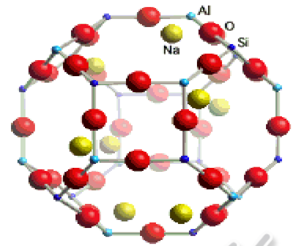
$$n(\mathrm{Si_2O_5,Al_2O_2}) + 2n\mathrm{SiO_2} + 4n\mathrm{H_2O} + \mathrm{NaOH/KOH} \rightarrow \mathrm{Na^+,K^+} + n(\mathrm{OH})_3 -\mathrm{Si}-\mathrm{O}-\underset{\underset{(\mathrm{OH})_2}{|}}{\mathrm{Al^-}}-\mathrm{O}-\mathrm{Si}-(\mathrm{OH})_3$$

(Si – Al material) (Geopolymer precursor)

$$n(\mathrm{OH})_3-\mathrm{Si}-\mathrm{O}-\underset{\underset{(\mathrm{OH})_2}{|}}{\mathrm{Al^-}}-\mathrm{O}-\mathrm{Si}-(\mathrm{OH})_3 + \mathrm{NaOH/KOH} \rightarrow (\mathrm{Na^+,K^+})-(-\underset{\underset{\mathrm{O}}{|}}{\overset{|}{\mathrm{Si}}}-\mathrm{O}-\underset{\underset{\mathrm{O}}{|}}{\overset{|}{\mathrm{Al^-}}}-\mathrm{O}-\underset{\underset{\mathrm{O}}{|}}{\overset{|}{\mathrm{Si}}}-\mathrm{O}-) + 4n\mathrm{H_2O}$$

(Geopolymer backbone)

3D Interlocking structure



Sodium-Poly(sialate)
Sodalite framework Na-PS

Advantages of geopolymer

Geopolymerization is one of the cost effective and environment friendly process routes for converting different types of industrial rejects in to useful materials, especially building units.

No heating/firing

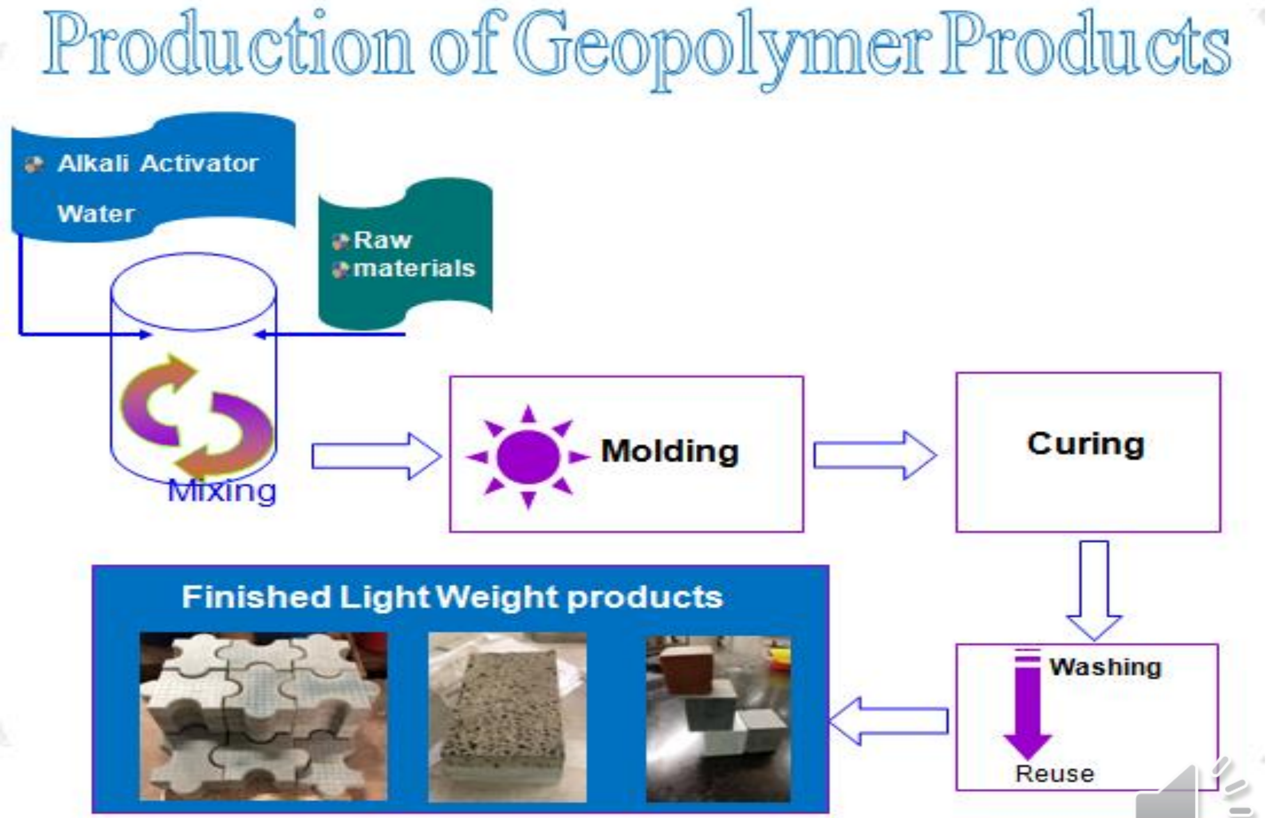
Geopolymer

No emission

Binding without cement

Synthesis of geopolymer

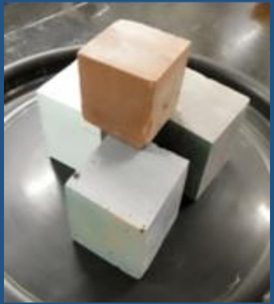
Geopolymer products



Geopolymer product range

Many industrial rejects has been studied and knowledge data base has been created for its conversion into sustainable building products for civil engineering applications

- Non fired geopolymer blocks
  - Light weight
  - Hard
  - Foam type
  - Sandwich type
- Light weight structural units



FEATURES

- Non fired (geopolymer) blocks
- Curing at room temperature
- Porous layers holds all through air cavities
- Air being poor thermal conductor, it restrict heat exchange with surroundings when used as building material

- The hard layers are strong and required crushing strength
- shall be imparted by means of fiber reinforcing / changing material composition / activator concentration
- Geopolymer is fire resistant
- Termite resistant
- Binding without cement

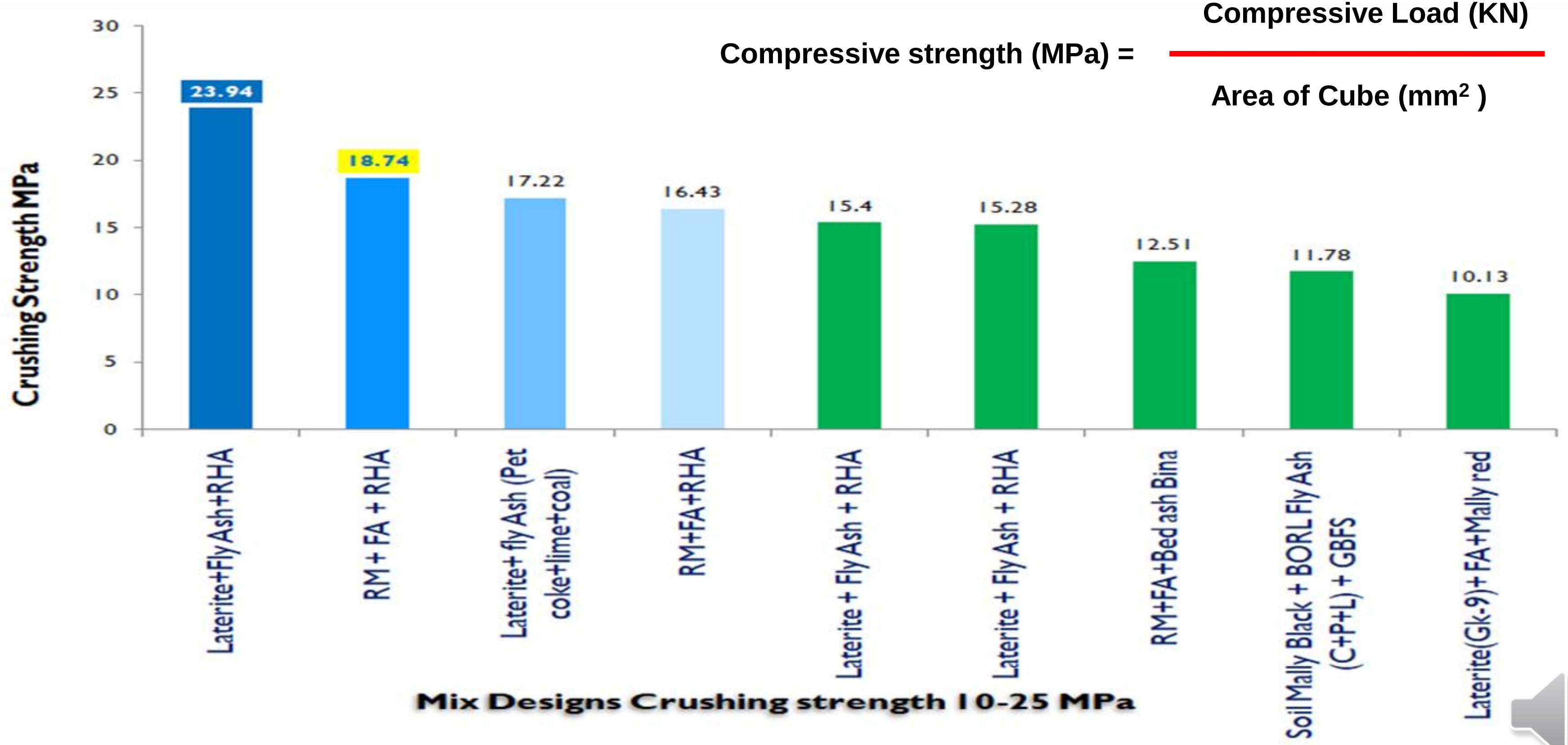
Strength of geopolymer

Strength of geopolymer products depend on the concentration of activator medium, materials composition and ratio of components in mix design

Crushing strength with mix composition and activator concentration

Composition (w/w)	Activator Con.(v/v)	Dry Density (Kg/m^3)	Crushing Strength (MPa)
Red Mud + Fly Ash + RHA (50:25:25)	12: 10 (1:1)	1530.46	14.78
Red Mud + Fly Ash + RHA (50:25:25)	10: 2.5 (1:1)	1525.38	05.75
Red Mud + Fly Ash (50:50)	10: 6.0 (1:1)	1905.45	06.72
Red Mud + Fly Ash + RHA (30:30:40)	08: 6.0 (1:1)	1376.36	04.80
Red Mud + Fly Ash + RHA (30:30:40)	08: 2.5 (1:1)	1408.98	05.12
Red Mud + Fly Ash + RHA (40:40:20)	08: 2.5 (1:1)	1723.23	03.72
Activator concentration: In moles			

Crushing Strength vs. Mix Design



$$\text{Compressive strength (MPa)} = \frac{\text{Compressive Load (KN)}}{\text{Area of Cube (mm}^2\text{)}}$$

Critical parameters

Parameter	Description
• Crushing strength	Compressive strength of geopolymer increases with increase of molarity of alkali activator and curing temperature
• Water absorption	Water absorption depend on the curing temperature and dry mix composition (Physical synergy of material)
• Efflorescence	Increase in molarity and decrease in curing temperature Efflorescence of geopolymer increases. Synergy of Material also critical
• Density	Density of geopolymer not depend on concentration of activator, it depend on the nature of raw material composition

Embodied energy and carbon

Construction is the 2nd largest industry in this world.

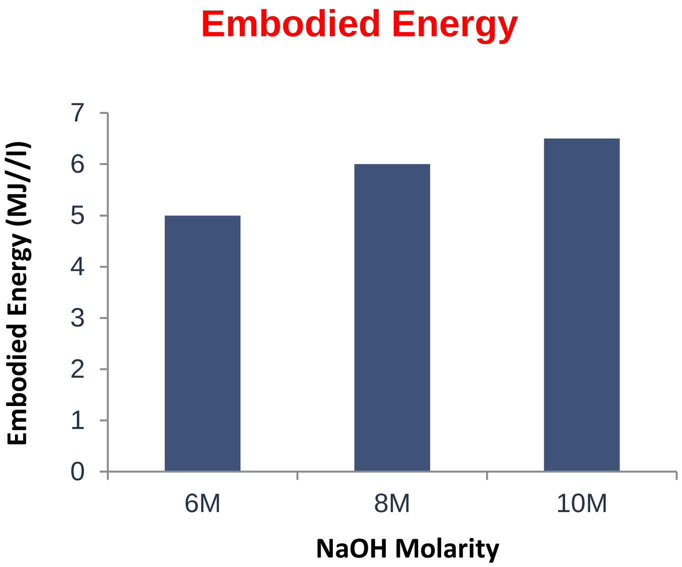
Embodied energy, carbon emission, economy, utility, durability and comfort are the main concerns of current classical building design.

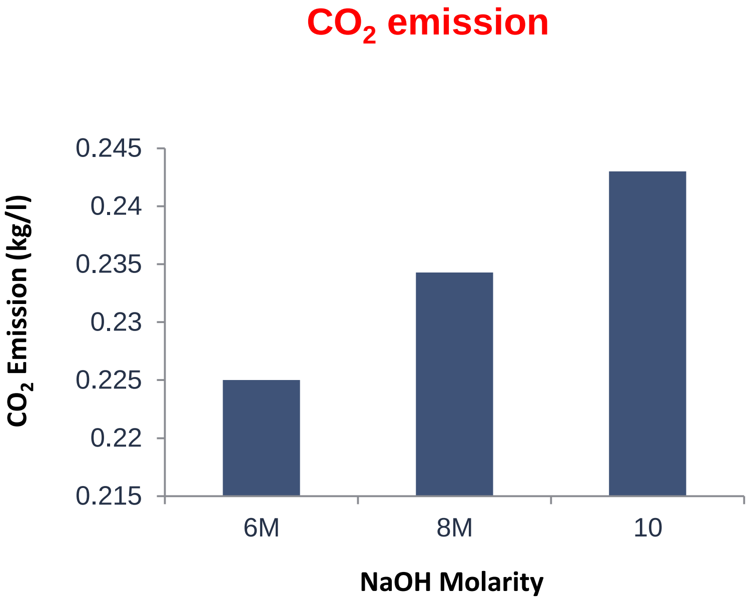
In order to reduce the carbon footprint of infrastructure it is important to account the energy that is embodied in the materials that we use.

"Embodied Energy" (EE) is the sum of energy requirements associated directly or indirectly with the delivery of goods or services (includes the energy used to extract, manufacture, and transport all the materials to be used)

For the over all analysis of developed geopolymer, it is observed that with the increase in the sodium hydroxide molarity the compressive strength, embodied energy and CO_2 emission increases.

NaOH molarity v.s. EE and CO_2 emission





Role of mineral phase

The XRD data (mineralogy) of materials is useful for choosing the right combinations of raw materials based on the presence of active mineral phase with in the component oxide viz. the prominence of crystalline quarts and amorphous silica in total SiO_2 as well as more active gibbsite [$Al(OH)_3$], less active boehmite [$AlHO_2$] and least active diaspore [AlO(OH)] minerals usually present in low grade bauxite, overburden laterite and other clay mineral rejects at different ratios in total Al_2O_3 for alkali activation at ambient conditions.

This information of active mineralogical phases (from XRD analysis) with in the specific mineral oxide (from chemical analysis) is also useful for measured use of alkali activator (Na_2SiO_3 and NaOH) for geopolymerization.

The reserved use of alkali activator in geopolymer facilitate better economics and quality of geopolymer products. Proper use of alkali for activation of active mineral phases in the raw material marks low efflorescence and material strength by encapsulating the less or non-active mineral components with in the geopolymer three-dimensional structures based on the tetrahedrons sharing of active Al and Si atoms

Comparison of geopolymer with clay products

Physical properties of overburden laterite (OBL) based geopolymer brick was compared with the commercially available burnt clay (BC) and fly ash (FA) bricks. The comparison showed that the density of OBL bricks is 12.5% and 22.2% lower compared to the BC and FA bricks, respectively.

The achieved compressive strength of OBL at ambient temperature is far more than that of burnt clay and fly ash bricks, which will ultimately help in saving energy required in case for heat curing.

Overall, the developed geopolymer brick using laterite as primary raw material resulted in performance improvement. Wherever higher strength of brick is the criteria, these geopolymer bricks can be conveniently used for the construction purpose.

Geopolymer brick Vs burnt clay, fly ash cement bricks

Brick type	Material composition (wt %)					Physical Properties		
	CL	FA	LT	SD	CM	Density (kg/m^3)	Compressive Strength (MPa)	Water Absorption (%)
BCB	90	-	-	10	-	1600	03.5	15
FAB	-	40	-	50	10	1800	06.5	10
OBL	-	25 + RHA	50	-	-	1401	23.94	15

BCB: Burnt clay brick; FAB: Fly ash brick; Lat`1B: Laterite brick (geopolymer); CM: Cement, SD: Sand

Inference of the case study

Compressive strength of the OBL geopolymer bricks is as high as 23 MPa. The water absorption and efflorescence are well within the permissible limit given by Indian standards.

Compared to burnt clay and fly ash brick, the basic properties geopolymers blocks developed shows that it can be used in building and construction (as a substitute for burnt bricks products) depending on the purpose and engineering models.

Apart from that the described process, geopolymerization can contribute significantly to environmental preservation, since there is a practical possibility of converting large quantity of alumino-siliceous industrial rejects as alternate building materials.

This mineral rich resource needs to be exploited with respect to the chemical and mineralogical parameters for developing value added products at ambient condition thus saving energy, environment and natural mineral resources for future needs.

Toxic immobilization by geopolymerization

Toxic or radio active comports (REs) in the rejects like low grade bauxite or red mud of certain geological origin can be contained in the geopolymer matrix for safe disposal in deep seabed or soil for long

3D printing

It involve spraying powders of alumino-siliceous materials layer by layer on the substrate onto which an alkaline solution will be sprayed for activation nd strength development .

Geopolymer ceramics

Geopolymer material with a low calcium content holds great potential for future ceramic applications. Zirconia-reinforced geopolymer matrices produce materials with enhanced compressive, fracture toughness, crack resistance, and thermal stability.

CONCLUSION

- Geopolymerization is useful for making wide range of building materials without firing and emission of green house gases.
- Building & construction industry posses the space for consuming largest volume of industry rejects as geopolymerized building materials.
- Solid rejects of aluminium industry origin are best suits for making wide variety of building materials with or without the addition of materials from other sources.
- Chemical and mineralogical data of raw material need to be considered for making mix designs of geopolymer product for reduced use of commercial ingredients as alkali activator
- Since the Embodied energy and overall CO_2 emission is directly proportional to the alkali activator composition, calculated use of NaOH is advised for making activator composition.
- Scope and use of geopolymer as a reliable medium for containing heavy metal pollutants, radioactive elements and other toxic components for safe disposal need to be investigated.

Relevant patent & publications from JNARDDC

Effort by JNARDDC, Nagpur for awareness, publicity & commercialization of Geopolymer products

Research Publications and Patent from JNARDDC, Nagpur, India on Solid Rejects of Aluminium Industry

Research Publications

1. Assessment of Aluminum Industrial Wastes: Synergistic Utilization for Production of Geopolymeric Building Materials; P.A.Mohamed Najar, M.J.Chaddha, P.G.Bhukte, K.R.Rao, K.Janbandhu, M.T.Nimje, S.P.Puttewar, A.Agnihotri and S. Jain, International Seminar on "Emerging Building Materials and Construction Technologies", BMTPC, New Delhi during March 21-22, 2016.
2. Study on the Effect of Molar Concentration of Alkali Activator and Compositional Variation of Raw Materials on Compressive Strength of Geopolymer Bricks; Shama Vadsariya, Numanuddin Azad, P.A.Mohamed Najar, M.J.Chaddha, P.G.Bhukte, S.P.Puttewar and A.Agnihotri, National Seminar on "Geopolymer an Innovative Technology in Civil Engineering Materials", Christ University, Bangalore, February 23-24,2017.
3. Assessment of Physical Characteristics of Low Temperature Geopolymeric Building Bricks; Numanuddin Azad, Shama Vadsariya, P.A.Mohamed Najar, M.J.Chaddha, P.G.Bhukte, S.P.Puttewar and A.Agnihotri, National Seminar on "Geopolymer an Innovative Technology in Civil Engineering Materials", Christ University, February 23-24,2017.
4. Assessment and Utilization of Industrial Wastes for Geopolymers; K.J. Kulkarni, P.A.Mohamed Najar, M.J.Chaddha and A.Agnihotri, National Seminar on "Geopolymer an Innovative Technology in Civil Engineering Materials", Christ University, February 23-24, 2017.
5. Potential of Aluminium Industrial Rejects Towards Geopolymeric Building Materials; P.A.Mohamed Najar, M.J.Chaddha, P.G.Bhukte, Vishakha Sakhare, Numanuddin Azad, Shama Vadsariya, K.R.Rao, K.Janbandhu, M.T.Nimje, S.P.Puttewar, A.Agnihotri and S. Jain, National Seminar on "Geopolymer an Innovative Technology in Civil Engineering Materials", Christ University, February 23-24, 2017.
6. Geopolymeric Building Material from Aluminium, P.A.Mohamed Najar and M.J.Chaddha, MMR, January, 2017.
7. Cost Effective Recovery of Iron from Steel Industry Rejects and Utilization of Rest for Building Materials: Scope of Green Process Route, Mohamed Najar, Shama Wadsariya, Numanuddin Azad, Suresh Puttewar and Anupam Agnihotri
8. Utilization of Industry Rejects: Application of Green Process Routes for Beneficiation of Iron and Preparation of Building Materials, Mohamed Najar, Shama Wadsariya, Numanuddin Azad, Paresh Nageshwar, Kiran Janbandhu, Pravin Bhukte, Suresh Puttewar and Anupam Agnihotri, 20th Convention of IGC on "Make in India: Challenges and Opportunities for Domestic Iron and Steel Industry and Its Innate Mineral-Raw Materials", October 3-5, 2017 at Nagpur
9. Utilization of Metallurgical Solid Wastes for Development of Construction Materials Based on Green Process Route; M.J. Chaddha, P.A. Mohamed Najar, Shama Wadsariya, Numanuddin Azad, K.J. Kulkarni and A. Agnihotri M.J. Chaddha, P.A. Mohamed Najar, Shama Wadsariya, Numanuddin Azad, K.J. Kulkarni and A. Agnihotri, WWMMI-2018 to be held at IIMT Bhubaneswar during March,2018.
10. Development of Sustainable Construction Materials: Value Addition and Utilization of Industrial Rejects for Resource Augmentation; P.A.Mohamed Najar, P.G. Bhukte, Numanuddin Azad, M.J.Chaddha, M.T. Nimje, S.P.Puttewar and A.Agnihotri, MEAI-IBM International Conference ,November 2017
11. Processing of Bauxite Mine Wastes for Value Added Products; Pravin G Bhukte, Mohamed Najar, G Daware, S P Puttewar, & A Agnihotri, MEAI-IBM International Conference , December 2017.

12. Assessment of Physical and Chemical Characteristics Geopolymeric Building Materials Developed from Steel Industry Rejects; P A Mohamed Najar, Numanuddin Azad, Shama Wadsariya, K R Rao, M J Chaddha, S P Puttewar and A Agnihotri, NMD-ATM 2017, Goa, November -2017.
13. Development of Sustainable Construction Materials: Value Addition and Utilization of Industrial Rejects for Resource Augmentation; Green Ashcon, December 2017, Nagpur
14. Utilization of Metallurgical Solid Wastes for Development of Construction Materials Based on Green Process Route; M.J. Chaddha, P.A. Mohamed Najar, Shama Wadsariya, Numanuddin Azad, K.J. Kulkarni and A. Agnihotri WWMMI-2018 IIMT, Bhubaneswar, March,2018.
15. Value-Added Geopolymer Products to Offset Expenditure on Waste Management and Sustainability, P A Mohamed Najar, Vishakha Sakhare, Shama Wadsariya, Numanuddin Azad, Sneha Dwivedi, Amrita Karn, P.G. Bhukte, S P Puttewar and A Agnihotri, for INCAL-2019, Bhubaneswar.
16. Supporting Low-Carbon Infrastructure: Consolidation of Industrial Rejects by Geopolymerization and Immobilization of Toxic Components for Utilization, P A Mohamed Najar, Vishakha Sakhare, Amrita Karn, Sayali Waghmare, S P Puttewar and A Agnihotri, IBAAS 2019
17. Recycling of industrial rejects of value addition and resources augmentation, Mohamed Najar, Amrita Karn and Paresh Nageshwar, J. Mater. Recycl., MRAI, 1 (2) (2019), pp. 50-53.
18. Development of Sustainable Construction Materials: Value Addition and Utilization of Industrial Rejects for Resource Augmentation, P.A.Mohamed Najar, Numanuddin Azad, P.G. Bhukte, M.J.Chaddha, S.P.Puttewar and A. Agnihotri, International Conference on and Expo on Mining Industry Vision 2020 & Beyond , Nagpur
19. A study on the impact of material synergy in geopolymer adobe: Emphasis on utilizing overburden laterite of aluminium industry, Mohamed Najar, Vishakha Sakhare, Amrita Karn, Mukesh Chaddha and Anupam Agnihotri; Open Ceramics, Science Direct, Elsevier, 7, 2021, 100163.
20. Non-reinforced high strength geopolymer from industrial rejects for sustainable engineering, Mohamed Najar, Vishakha Sakhare, Numanuddin Azad, Amrita Karn, Mukesh Chaddha and Anupam Agnihotri, CHEMCON-2021, Kolkata.
21. Value-Added Geopolymer Products to Offset Expenditure on Waste Management and Sustainability, P A Mohamed Najar, Vishakha Sakhare, Amrita Karn, M.J. Chaddha, A Agnihotri, Journal of Chemical Technology and Metallurgy, Bulgaria, 57, 1, 2022, 141-152.

Book chapter

1. Value Addition of Alumino-Silicates: Consolidation of Mining Rejects and Industrial Slag by Geo-Polymerization, Innovations in Sustainable Mining, Mohamed Najar, Amrita Karn, Vishakha Sakhare, Mukesh Jitsingh Chaddha, Anupam Agnihotri, Springer, Cham, 57-70, 2021

Patent

Patent No. 409005, 12/10/2022

A light weight foamed geopolymer (LWFGEOP) and its preparation, Mohamed Najar, Numanuddin Azad, Shama Wadsariya, M J Chaddha, P G Bhukte, S P Puttewar, Anupam Agnihotri and Saket Jain

Commercialization & Technology Transfer

M/s Swarnalatha Holdings is setting up the production unit at Raipur, India

Conference/Seminar

A national seminar "**Geopolymer based Innovative Technologies in Civil Engineering Materials** "organized at Christ University, at Bangalore Campus during 23-24th February 2017. Three research papers presented based on the project (research) work

Invited talks / lectures /Keynote address

1. Aluminium Industrial Rejects: A Potential Resource for Development of Geopolymeric Building Materials, Christ University, Bangalore 2017.
2. Development of Sustainable Construction Materials: Value Addition and Utilization of Industrial Rejects for Resource Augmentation; MEAI-IBM International Conference, November 2017
3. Expert Lecture of AICTE Sponsored STTP on "Current Environmental Challenges & Their Remedies in Science and Engineering: A Multidisciplinary Approach" Industry & Environment: Consolidation of Industrial Rejects by Geopolymerization and Immobilization of Toxic Components for Supporting Low-Carbon Infrastructure, Mohamed Najar, at Department of Chemical Engineering, Priyadarshini Institute of Engineering and Technology 26th September 2019, Nagpur.

Preparation of light weight foamed geopolymer at JNARDDC

Preparation of light weight foamed geopolymer (Red mud + Fly ash 1:1w/w)

Thank You

सत्यमेव जयते
Ministry of Mines
Government of India

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