Red Mud-based Geopolymer Concrete as an Emerging Construction Material for a Sustainable Future: A Review

Nikita Barik[1*], Jyotirmoy Mishra[2]

[1*] M. Tech, Department of Civil Engineering,
College of Engineering and Technology, Bhubaneswar, Odisha, India.
nikitabls11@gmail.com

[2] Ph.D. Scholar, Department of Civil Engineering,
Veer Surendra Sai University of Technology, Burla, Odisha, India.
jmishra_phdce@vssut.ac.in

Abstract*: Sustainable waste management is important so that every bit of waste can be managed in a structured manner and the waste created is kept to a minimum. The development of geopolymer concrete is one of the steps towards achieving this objective. Geopolymer concrete, which is produced by copolymerization of aluminosilicate materials (source materials) with alkaline solutions, exhibits higher mechanical strength and excellent durability properties when compared to the traditional cement-based concrete, leading to a sharp reduction in the greenhouse gas emissions at lower operating costs. Several aluminosilicate industrial wastes such as fly ash (FA), ground granulated blast furnace slag (GGBFS), metakaolin (MK), ferrochrome ash (FCA), red mud (RM), can be used as source materials for geopolymer concrete production. This paper carries out a review on properties of red mud-based geopolymer concrete. Red mud is a waste generated from the alumina refining industry, and is considered hazardous due to its high alkalinity. Apart from this, it contains significant amount of oxides of aluminum, silicon, and iron and is therefore considered to be beneficial for geopolymerization. The rapid utilization of red mud in the production of geopolymer concrete is highly anticipated in near future. Hence, this paper outlines the mechanical and durability properties of red mud-based geopolymer concrete from past literature, which will provide a technical framework for conducting future experimental works, leading to its commercialization.

***Keywords*: geopolymer; geopolymer concrete; waste management; red mud**

(Article history: Received: 19th January 2021 and accepted 11th June 2021)

I. INTRODUCTION

One of the vital problems witnessed by the world today is the degradation of our environment. Due to rapid industrialization in the developing countries, a huge amount of industrial solid wastes is generated and its rate is increasing each year. These wastes can be considered to have adverse effects worldwide as they may contaminate the environment if not treated or disposed of properly. In this context, sustainable industrial waste management is crucial and is the need of the hour [1].

A major component of concrete is cement, basically known as Ordinary Portland cement (OPC). The production of cement causes extensive energy consumption, noise pollution, environmental heating, and emissions of greenhouse gases (5% of global CO_2 emissions) through the combustion of fossil fuels, as well as through the decarbonization of limestone [2][3]. Furthermore, carbon emissions affect the planet significantly, as they cause global warming that ultimately leads to climate change issues.

Hence, it is necessary to find alternative methods of manufacturing concrete based on renewables and recycled materials. Geopolymer concrete is an innovative construction material which is produced by mixing various aluminosilicate materials with alkaline solutions to form geopolymer paste that binds the aggregates and other un-reacted materials together [4]. It has the potential to positively contribute to environmental sustainability in both the industrial and construction sectors, through the recycling of waste materials and the reduction in carbon emissions. In the last decade, lots of research works have been carried out to investigate the engineering properties of geopolymer concrete. Results from previous works indicate that geopolymer concrete has more benefits over conventional cement-based concrete such as high mechanical strength, lower shrinkage characteristics, and superior durability properties. Nowadays, geopolymer concrete is progressively used in civil construction works, such as structural buildings, precast bridge decks, etc. because of its structural and economic benefits [5].

Industrial solid waste is defined as waste generated from manufacturing processes. Some of the industrial wastes are fly ash (FA), GGBFS (ground granulated blast furnace slag), ferrochrome ash (FCA), red mud (RM), and rice husk ash (RHA). These wastes are used as source materials to produce geopolymer as it contains high silica and alumina content [6]. Recycling industrial wastes can facilitate the development of eco-friendly construction materials such as geopolymers, leading to a sustainable future.

This paper establishes a review on red mud (RM) based geopolymer concrete. RM, a bauxite residue, is a waste product composed of a significant amount of alumina, silicon, and iron oxides, generated from the alumina refining industry [7]. Due to its high alkalinity, it can pose a significant environmental hazard. As a result, significant efforts need to be taken in finding better methods for dealing with it. Potential applications of RM include: improvement of soil acidity, landfill capping, and as a source material for geopolymerization. The large-scale recycling of RM through geopolymerization will result in achieving sustainability goals. This study, therefore attempts to comprehensively review the mechanical and durability properties of RM-based geopolymer concrete.

II. Red mud and its properties

RM is the by-product produced from the alumina refining of bauxite ore. Depending on the quality and purity of the bauxite ore, the quantity of RM generated varies from 55% to 65% of the processed bauxite [8]. Hausberg et al. [9] reported that for every ton of alumina, the volume of RM generated is between 1-1.5tons [23]. More than 4 million tons of RM is generated annually in India only [10]. Annual production of aluminum led to an annual global production of RM accumulated to reach 2.7 billion tons worldwide [11]. In the Bayer process, strip-mined bauxite is treated with hot caustic soda (sodium hydroxide), which carefully dissolves aluminum from an array of other mineralized metals. The end product is alumina (Al_2O_3), which is the intermediate for producing aluminum metal. Bauxite processors recycle the caustic soda and pump the residual RM sludge into huge settling ponds. But RM is strong enough to kill plant and animal life and causes burns and damages to lungs if the fumes are respired. Hence, RM is neutralized with seawater before it is used for construction materials production i.e. building panels, concretes, bricks, ceramic foam, foamed insulating bricks, tiles [12, 13, 14, 15, and 16].

A. *Physical Properties*

The particle size and density values have significant influences on the performances of RM as the raw materials for concrete production. The particle size distribution of the RM at a calcined temperature is in the range of 26.7 µm to 38.2 µm. Besides, the specific gravity of RM determined by the pycnometer method is 2.64. The measured value of the density of RM is 2.70g/cm^3 [18]. The fineness of RM is ranged between 1000-3000 cm^2/gm using Blaine's apparatus [19] [20]. The mud is highly basic with a pH, normally >12 which helps in boosting the geopolymerization process [21].

B. *Chemical Properties*

The percentage of oxides produced by a particular alumina refinery will depend on the quality and nature of the bauxite ore and the extraction conditions. The main chemical compositions of RM are: Fe_2O_3, Al_2O_3, SiO_2, CaO, Na_2O, TiO, K_2O, MgO, MnO, P_2O_5, and a large variety of minor elements [22]. RM is rich in FeO (41%) which helps in building ferrosialate link, Na_2O (5.47%) greatly helps in the dissolution of raw feedstock [20]. As the CaO content is very low hence it has no cementitious properties but when it reacts with water and cement it starts gaining cementious properties [19]. The greatest challenges of the RM are chemical variability, since it demands a greater control of the process and consequently, increases the costs related to reutilization [22].

III. Properties of red mud based geopolymer concrete

A. *Workability*

Addition of RM to the geopolymer concrete significantly reduces the workability, due to the fineness of particles and also due to the high water-demand [24]. The workability of geopolymer concrete was found out using the slump test. The slump values obtained from using the proportion of RM and GGBFS (80%:20%; 70%:30%; 60%:40%) was 50mm, 40mm and 30mm [25]. The workability remains constant for samples containing up to 40 wt.% RM and 0.47–0.58 water/geopolymer binder ratio [26]. The temperature of hydration escalated as more RM was added into the geopolymer concrete mixes, which led to strength enhancement in early ages and consequently the workability decreased [27].

B. *Compressive Strength*

From the experimental works, it was found that a higher amount of RM content in the geopolymer mix, decreases the compressive strength of the geopolymer concrete [28] [29]. For each percentage replacement, it is noted that there was 2.5%-5% increase in compressive strength, however, beyond 20% RM replacement, the strength decreased significantly [30]. The test results showed that the 28-day compressive strength of the geopolymer specimens containing 25% RM was found to be 29.5% lesser than that of reference concrete. In another study, RM-FA based geopolymer concrete exhibited compressive strengths over 17 MPa after curing for 14 days [31]. As RM is rich in FeO, the generated ferrosialate geopolymer network showed 53.34% increase in compressive strength when compared to traditional sialate geopolymer networks formed from FA alone. In a study, it was found that the geopolymer mixes containing RM, FA and GGBFS can be used as sustainable alternative material as the compressive strength of resulted geopolymer concrete was found to be 89.4% more than that of conventional cement-based concrete [32].

C. *Flexural strength*

The flexural strength test is one of the most common tests conducted on hardened concrete; this determines the resistance to flexing or stiffness of a material. It was found that as the percentage of RM (10%, 15%, 20%, and 25 %) increased, the flexural strength decreased. An increase in the content of RM decreases the workability and the packing effect reduces, thereby leads to the reduced strength and causing the material to be porous [17]. From the experimental results, it can be concluded that at optimum percentage of RM, the geopolymer concrete specimens gains more flexural strength when compared to conventional concrete [25].

D. *Durability*

Geopolymer paste containing 30% and 50% RM showed superior resistance to acid attack [33]. The introduction of

RM in the geopolymer mixes increases its resistance to sulphuric acid because of lesser calcium content and greater alkalinity [34]. The addition of RM up to 30% increases the resistance of the geopolymer specimens to both acetic acid and sulphuric acid solution. RM proved to be a promising raw material for production of geopolymer concrete since it inhibited the corrosion process [35]. The higher the content of RM, lower is the corrosion rate, which reached stability between 20-30% of RM content in the geopolymer mixes [36].

IV. CONCLUSION

The main objective of this paper was to review properties of a sustainable eco-friendly construction material i.e. RM-based geopolymer concrete. RM showed acceptable characteristics for its potential reuse as a civil engineering material. RM has the ability to be used in geopolymerization due to the presence of oxides of iron, silicon, and aluminium. Past studies suggested that it is an effective candidate to be used in the production of geopolymer concretes for construction purposes. Due to its sustainability characteristics, durability and strength properties - the RM-based geopolymer concrete can be used as an alternative construction material for a greener and sustainable future.

ACKNOWLEDGMENT

The authors would like to thank: Prof. Sanjaya K. Patro, Dr. Bharadwaj Nanda, Dr. Syed M. Mustakim, Mr. Shaswat K. Das & Mr. R.S. Krishna, for their encouragement and motivation during the conduct of this study.

REFERENCES

[1] Dr. Haggar, "Sustainable Industrial Design and Waste Management cradle-to-cradle for sustainable development," Elsevier Academic Press, 2007.

[2] T. Gasser, E. Terrenoire , D. Hauglustaene and O. Penanhoat , "The contribution of carbon dioxide emissions from the aviation sector to future climate change," Environmental Research Letters, vol. 14, no.8, 2019.

[3] J. Davidovitis , "Geopolymers," Green Chemistry, and Sustainable development solutions, Proceedings of the Geopolymer, 2005.

[4] S. Das , J. Mishra and S Mustakim, " An Overview of Current Research Trends in Geopolymer Concrete," International Research Journal of Engineering and Technology, vol. 05 Issue 11,2018.

[5] A. Aleem and P. Arumairaj , "Geopolymer concrete- A review," International Journal of Engineering Sciences& Emerging Technologies 1(2): 118-122, 2012.

[6] P. Rana , R. Dash and Ganguly R., "Geopolymer from Industrial Wastes: A Construction Material for 22nd Century," Advanced Composites for Aerospace, Marine and Land Applications, pp.43-54.

[7] Q. Nie , Hu W. , A. Tao, B. Huang X. Shu and Q. He, "Strength properties of geopolymers derived from original and desulfrurized RM cured at ambient temperature," Construction and Building Materials, pp.905-911,2018.

[8] G. Zhang , J. He and R. Gambrell, "Synthesis, Characterization and Mechanical Properties of RM-Based Geopolymers," Journal of the Transportation Research Board 2167(1): 1-9, 2010.

[9] J. Hausberg,U. Happel, F.M.Meyer, M.Mistry, M. Rohrlich, H. Koch, P.N.Martens, J. Schlimbach, G. Rombach and J.Kruger, "Global RM reduction potential through optimized technologies and ore selection," Mineral Resources Engineering 09(04): pp.407-420, 2000.

[10] S. Samal, A. Ray and A. Bandopadhyay , "Proposal for Resources, Utilization and Processes of RM in India- A Review," International Journal of Mineral Processing 118,pp.43-55, 2013.

[11] S. Ahmed , T. Meng and M. Taha , "Utilization of RM for producing a high strength binder by composition optimization and Nano strengthening," Nanotechnology Reviews, vol. 9: issue 1, 2020.

[12] Y. Pontikes and G. Angelopoulos , "Bauxite residue in cement and cementious material," Resourc. Conserv. Recyl. 73, 53-63, 2013.

[13] M. Singh, SN Upadhayay and M. Prasad, "Preparation of special cements from RM," Waste Manag 16(8), pp.665-70, 1996.

[14] E. Tsakiridis , S. Agatzini-Leonardou and P. Oustadakis, "RM addition in the raw meal for the production of Portland cement clinker," 116(1-2), pp.103-10,2004.

[15] M. Singh , SN Upadhayay and M. Prasad, "Preparation of iron rich cements using RM," Cement Concr Res. 27(7), pp.1037-46, 1997.

[16] X. Chen , A. Lu and G. Qu , "Preparation and characterization of foam ceramics from RM and fly ash using sodium silicate as foaming agent," Ceram Int. 39(2):1923-9, 2013.

[17] Arhin. Dodoo , R. Nuamah , T. Benjamin , D. OAbada and A. Yaya, "Awaso bauxite RM-cement based composites: Characterization for pavement applications," Case Studies in Construction Materials, Vol.7, pp.45-55, 2017.

[18] P. Wang and Liu Dong-Yan, "Physical and Chemical Properties of Sintering RM and Bayer RM and the Implications for Beneficial Utilization," Materials 2012, 5, pp.1800-1810, 2012.

[19] R. Rathod, N. Suryawanshi and P. Memade, "Evaluation of the properties of RM Concrete,", IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), pp.31-34, 2013.

[20] B. Yeddula and K. Somasundaram, "Effect of RM proportion on the strength and microstructure of ferrosialate based geopolymer mortar," Indian Journal of Engineering & Materials Sciences Vol. 27, pp.554-563, 2020.

[21] M. Grafe, G. Power and C. Klauber, "Bauxite residue issues: III.Alkalinity and associated chemistry," Hydrometallurgy: 108(1-2),pp.60-79, 2011.

[22] M., Lima ,L. Thives, V. Haritonovas and K. Bajars, "RM application in construction industry: review of benefits and possibilities," Materials Science and Engineering 251(2017) 012033, 2017.

[23] L. Hai, N. Khai, T. Quy and N. Huan, "Material Composition and Properties of RM coming from Alumina processing plant Tarnal, Lamdong, Vietnam," International Journal of Research In Earth & Environmental Sciences, Vol. 1(6), ISNN 2311-2484, 2014.

[24] C., Venkatesh M. Chand and R. Nerella," A State of the art on RM as a substitutional cementious material," International Information and Engineering Technology Association, Vol.43,pp.. 99-106, 2019.

[25] E. John, K. Chalapuram, P. Shebin, H. Mohan and Z. Frazana, "Geopolymer concrete using RM and GGBFS," International Research Journal of Engineering and Technology, Vol. 3, issue:05, e-ISSN: 2395-0056, 2016.

[26] Sneff, R. Modolo, V. Ferreira, D. Hotza, J Labrincha., "Influence of RM addition on rheological behavior and hardened properties of mortars," Construction and Building Materials 65, pp.: 84-91, 2014.

[27] S. Pujar and K. Prakash, "Effect of Replacement of Cement by RM on the Properties of Concrete,"International Journal of Scientific & Engineering Research, Volume 5(9) and ISSN 2229-551, 2014.

[28] S. Singh, R. Biswas and M. Aswath, "Experimental Study on RM Based Geopolymer Concrete with Fly Ash & GGBFS in Ambient Temperature Curing," International Journal of Advances in Mechanical and Civil Engineering, ISSN: 2394-2827, 2016.

[29] D. Nemade, "Evaluation of the properties of RM concrete," IOSR Journal of Mechanical and Civil Engineering, pp.31-34, 2013.

[30] P. Bishetti and L. Pammar, "Experimental study on utilization of industrial waste in concrete," International Journal of Technical Research and Applications, Vol.2, pp.49-52, 2014.

[31] Z. Yang, R. Mocadlo, M. Zhao, D. Richard, M. Tao and J. Liang,"Preparation of a geopolymer from RM slurry and class F fly ash and its behavior at elevated temperatures," Construction and Building Materials 221(2019),pp.308-317, 2019.

[32] S. Kulami, "Experimental Study on RM, Fly Ash and GGBFS based Geopolymer concrete A Green Substitute to Conventional Concrete,"

International Journal of Engineering Research & Technology, and vol.7 Issue 12, 2018.

[33] S. Singh, M. Uddappa and R. Ranganath, "Durability of RM based Geopolymer paste in acid solutions," Material Science Forum 866, pp.99-105, 2016.

[34] S. Singh, S. Basavanagowda, M. Aswath and R. Ranganath, "Durability of Bricks coated with RM based Geopolymer paste," Materials Science and Engineering 149 0102070, 2016.

[35] D. Ribeiro, J. Labrincha and R. Morelli., "Effect of the addition of RM on the corrosion parameters of reinforced concrete," Cement and Concrete Research 42(1):124-133, 2012.

[36] D. Ribeiro, J. Labrincha and R. Morelli., "Effect of RM addition on the corrosion parameters of reinforced concrete evaluated by electrochemical methods," Vol.5(4)pp.451-467, 2012.

AUTHOR PROFILE

Nikita Barik
She is currently pursuing M. Tech at Department of Civil Engineering, College of Engineering and Technology, Bhubaneswar, Odisha, India. She obtained her B. Tech degree from Government College of Engineering, Keonjhar, Odisha, India. She has presented her work at 3 major international conferences and have successfully published 2 journal articles. She is actively involved in upgrading her knowledge in the field of geopolymers.

Jyotirmoy Mishra
He is currently a full-time Ph.D. Scholar at Department of Civil Engineering, Veer Surendra Sai University of Technology, Burla, Odisha, India. He holds a B. Tech and M. Tech (Structural Engineering) - dual degree from KIIT University, Bhubaneswar, Odisha, India and has published over 25 research articles in various peer-reviewed journals in the field of geopolymers.