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An Experimental Investigation on Geo-Polymer Based Eco-Friendly GGBS and M-Sand Coarse Aggregates Using Pelletization Technique

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Abstract: ***This study investigates the manufacturing of eco-friendly coarse aggregates using Ground Granulated Blast Furnace Slag (GGBS) and M-sand through pelletization. Aggregates were prepared at varying molarities (4M, 6M, 8M) of alkaline activators under ambient and water curing conditions. Particle size distribution, bulk density, specific gravity, and water absorption were analyzed and compared with natural aggregates. Results indicate that pelletized GGBS aggregates exhibit comparable physical properties to natural aggregates, with improved sustainability benefits such as reduced CO_2 emissions and waste utilization. The findings highlight pelletization as a viable technique for producing durable, eco-friendly aggregates for sustainable construction.***

Keywords: GGBS, pelletization, geopolymer aggregates, sustainable construction, artificial coarse aggregates

1. Introduction

The construction industry is one of the largest consumers of natural resources, relying heavily on coarse aggregates such as gravel, sand, and crushed stone. However, the rapid depletion of these resources has raised significant concerns regarding sustainability, environmental degradation, and long-term availability. Quarrying activities not only disrupt ecological balance but also contribute to carbon emissions, land degradation, and loss of biodiversity (Ahmad et al., 2022).

In response, researchers have increasingly turned to alternative aggregates derived from industrial by-products. Among these, Ground Granulated Blast Furnace Slag (GGBS) has emerged as a promising candidate due to its cementitious properties, durability, and ability to reduce the carbon footprint of construction (Ingale, Rathod, & Agarwal, 2021; Patra & Mukharjee, 2021). Its utilization aligns with circular economy principles (Biswal & Dinakar, 2021).

Pelletization, which agglomerates fine particles into spherical pellets, improves handling, storage, and mechanical performance. It reduces dust formation, enhances bulk density, and ensures uniform particle size distribution, offering durable aggregates with minimized environmental impact (Bekkeri, 2023; Sunil et al., 2022).

2. Literature Review

- Geopolymer aggregates synthesized from industrial by-products such as fly ash and GGBS exhibit comparable strength and durability to natural aggregates, with optimized mix proportions and curing conditions significantly influencing mechanical performance (**Naveena & Narayana, 2022**).
- GGBS replacement up to 50% improves workability due to the fine texture of slag particles. Although compressive and tensile strengths show slower early gains, they exceed conventional concrete at later ages, with optimum performance around 50–60% replacement (**Ingale, Rathod, & Agarwal, 2021**).
- Alkali activation using sodium hydroxide and sodium silicate enhances binding properties and mechanical strength. Extended curing improves density and durability, while SEM analyses confirm improved microstructural bonding (**Kurzekar et al., 2024**).
- The synergistic effect of Metakaolin (MK) and GGBS improves compressive strength, resistance to sulphate and acid attacks, and reduces permeability, thereby enhancing durability while lowering cement consumption (**Tiwari et al., 2021**).
- Artificial aggregates produced using GGBFS, SSP, and fly ash through pelletization demonstrate high pelletization efficiency, reduced water absorption, and acceptable mechanical properties. SEM and XRD analyses confirm dense microstructures and hydrated gel products (**Bekkeri, 2023**).
- Fly ash-based lightweight aggregates show satisfactory strength and durability under proper curing, though high water absorption remains a challenge (**Sandeep, 2021**).
- Blending fly ash with GGBS reduces setting time and enhances compressive strength, particularly with higher molarities of alkaline activators (**Mallikarjun Rao et al., 2020**).
- Recycled aggregate concrete (RAC) combined with GGBS improves microstructure and reduces porosity, with 50% GGBS replacement yielding better strength and durability (**Biswal & Dinakar, 2021**).
- Partial substitution of natural sand with GGBS up to 40% maintains good workability and strength, while superplasticizers improve flow at higher replacement levels. GGBS enhances resistance to chemical attacks and supports sustainable construction (**Patra & Mukharjee, 2021**).
- Cold bonded pelletized aggregates using fly ash and slag are smoother and more spherical than conventional quartzite, with lower bulk density and specific gravity, confirming their potential as lightweight, sustainable alternatives (**Sunil et al., 2022**).

3. Materials and Methods

- **Materials:** GGBS, M-sand, NaOH, Na_2SiO_3.
- **Manufacturing Process:** Tilting drum mixer, pelletization, curing under ambient and water conditions.
- **Experimental Variables:** Molarities of 4M, 6M, 8M.
- **Testing Parameters:** Sieve analysis, specific gravity, water absorption, bulk density.
- **Benchmark:** Natural aggregates used for comparison.

4. Pelletization Process Flow

The manufacturing of GGBS-based coarse aggregates through pelletization follows a systematic sequence of operations. First, the raw materials — Ground Granulated Blast Furnace Slag (GGBS) and manufactured sand (M-sand) — are collected and prepared in predetermined proportions. These materials are then subjected to thorough dry mixing in a tilting drum mixer to ensure uniform blending. Once homogenized, alkaline activator solutions of varying molarities (4M, 6M, and 8M) are gradually added at controlled intervals. This step initiates the binding reaction and facilitates the formation of spherical or near-spherical pellets. The freshly formed pellets are shaped and stabilized through continuous rotation of the mixer, after which they are dried and cured under two regimes: ambient temperature curing and water curing. Finally, the cured aggregates undergo testing and analysis, including sieve analysis, specific gravity, bulk density, and water absorption, to evaluate their performance against natural coarse aggregates.

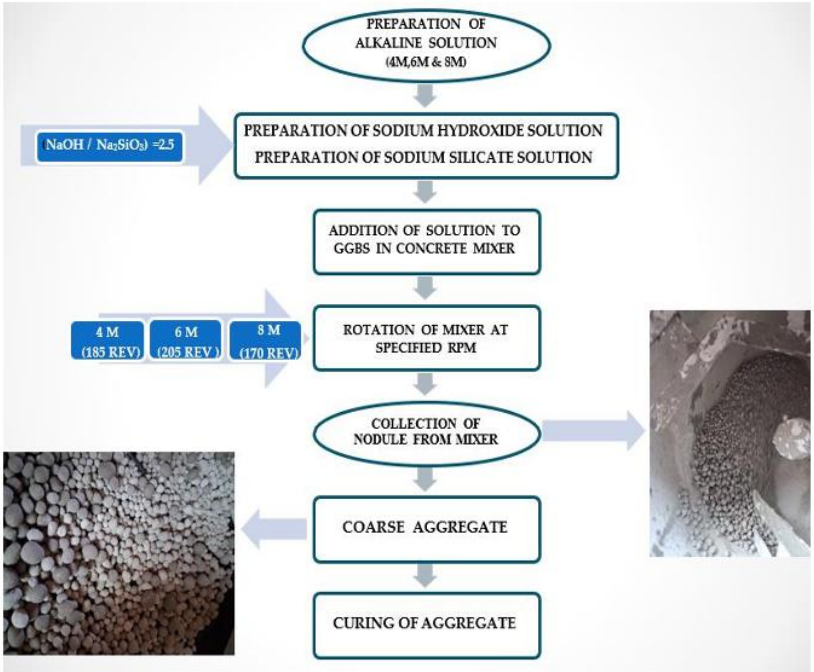

Figure 1: Experimental methodology to produce eco- friendly geo polymer based GGBS+M-sand coarse aggregates

5. Agglomeration Process

Agglomeration is the process by which fine particles are combined into larger, stronger pellets through binding mechanisms. In this method, binder droplets are first applied to the powder surface, which initiates the formation of liquid bridges between particles. As drying progresses, these liquid bridges transform into solid bridges, thereby increasing the strength and stability of the pellets. The result is a finished agglomerate with improved mechanical properties, reduced dust formation, and enhanced durability, making the material easier to handle and more suitable for construction applications.

The photograph of the aggregates depicts pelletized coarse aggregates produced from GGBS and M-sand, showing uniform spherical or near-spherical pellets of comparable size to natural aggregates (10–20 mm) with enhanced durability and reduced porosity.

6. Results and Discussion

- **Particle Size Distribution:** Pelletized aggregates achieved uniform grading comparable to natural aggregates.

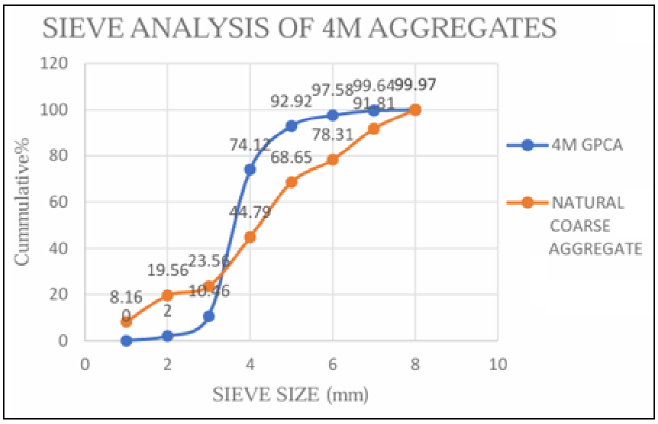

Figure 2: Sieve analysis of 4M Aggregates

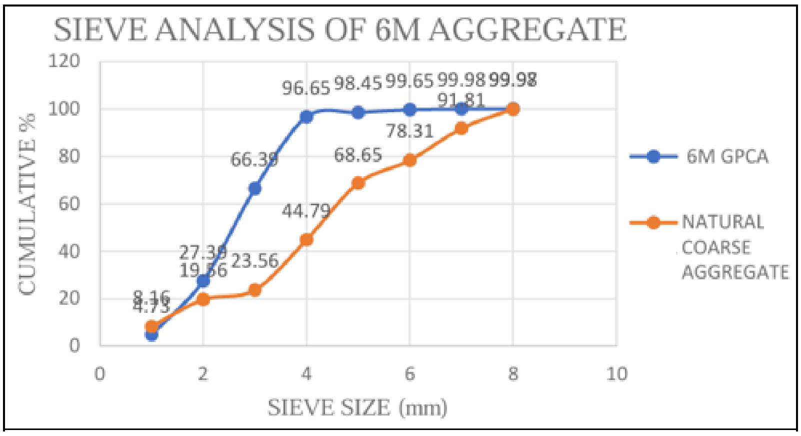

Figure 3: Sieve analysis of 6M Aggregates

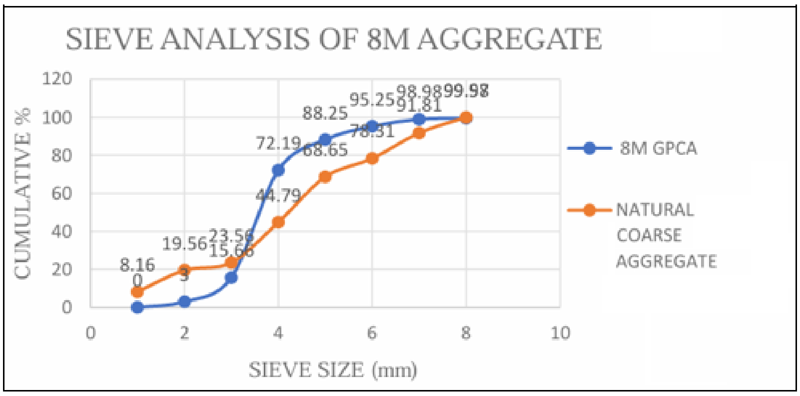

Figure 4: Sieve analysis of 8M Aggregates

The sieve analysis results demonstrate that pelletized aggregates produced at 4M, 6M, and 8M molarity achieved grading patterns comparable to natural coarse aggregates, confirming the effectiveness of the pelletization process in producing uniform particle sizes (**Sunil et al., 2022**). For the 4M GPCA, the distribution curve closely followed that of natural aggregates, though with slightly higher cumulative percentages at finer sieve sizes, indicating a marginally greater proportion of smaller particles. The 6M GPCA showed the most balanced gradation, with its curve aligning very closely with natural aggregates across the sieve range, suggesting that 6M molarity yields aggregates with optimal particle size distribution and uniformity (**Naveena & Narayana, 2022; Ingale, Rathod, & Agarwal, 2021**). In contrast, the 8M GPCA curve deviated more noticeably, particularly at intermediate sieve sizes, where higher cumulative percentages were observed. This indicates that 8M aggregates contained more fines, which may contribute to increased porosity and reduced strength compared to natural aggregates (**Mallikarjun Rao et al., 2020; Tiwari et al., 2021**). Overall, the findings highlight that while all pelletized aggregates achieved acceptable grading, the 6M GPCA provided the closest match to natural aggregates, making it the most suitable for practical applications in concrete production (**Patra & Mukharjee, 2021; Biswal & Dinakar, 2021**).

Comparison of 4M,6M and 8M with Natural coarse aggregate of Ambient curing

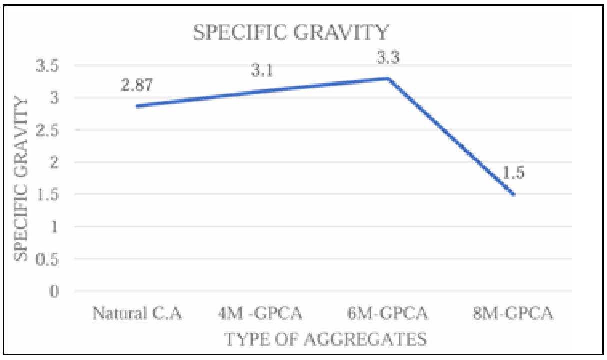

Figure 5: Specific gravity of 4M,6M and 8M with Natural C.A of Ambient curing

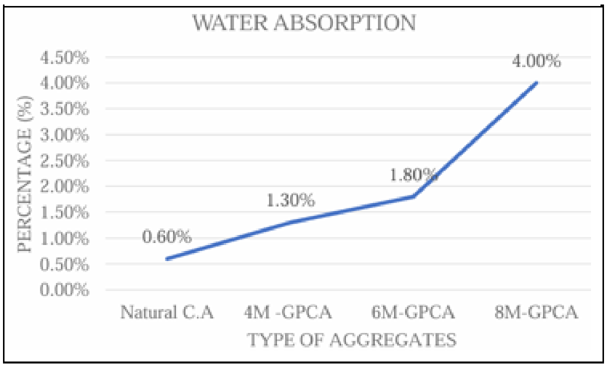

Figure 6: Water Absorption of 4M,6M and 8M Natural C.A of Ambient curing

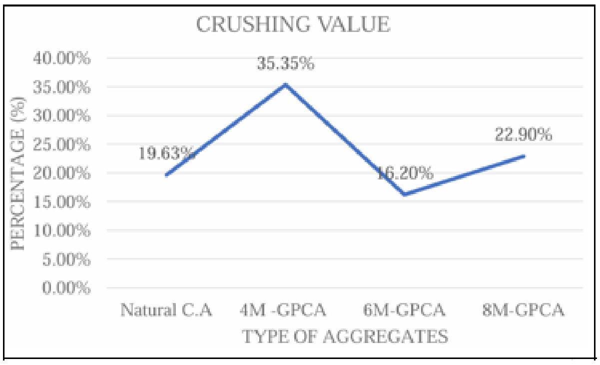

Figure 7: Crushing Value of 4M,6M and 8M with Natural C.A of Ambient curing

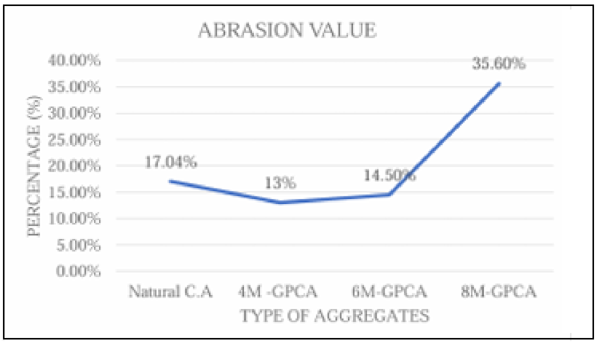

Figure 8: Abrasion value of 4M,6M and 8M with Natural C.A of Ambient curing

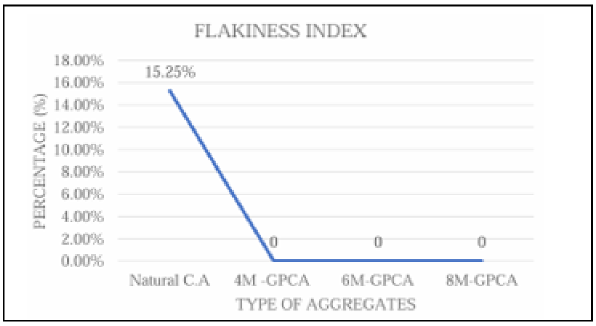

Figure 9: Flakiness Index of 4M,6M and 8M with Natural C.A of Ambient curing

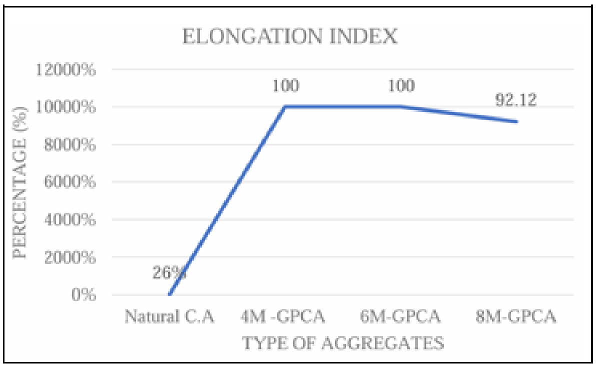

Figure 10: Elongation index of 4M,6M and 8M with Natural C.A of Ambient curing

Figure 11: GPCA Aggregates

The comparison of physical properties reveals that 6M aggregates performed most favorably, showing the highest specific gravity (3.3) and the lowest crushing value (16.20%), which indicates denser particles and superior strength compared to both natural aggregates and other GPCA mixes (**Ingale, Rathod, & Agarwal, 2021; Kurzekar et al., 2024**). Water absorption increased with molarity, reaching 4.0% at 8M, which suggests higher porosity and reduced durability, while natural aggregates maintained the lowest absorption at 0.60%. Similar increases in porosity with higher activator concentrations have been observed in geopolymer aggregate studies (**Mallikarjun Rao et al., 2020; Tiwari et al., 2021**). Abrasion resistance was better in 4M and 6M aggregates than in natural aggregates, though 8M aggregates exhibited poor resistance with a high value of 35.60%, consistent with findings that excessive molarity compromises durability (**Patra & Mukharjee, 2021**). A notable advantage of pelletized aggregates was the complete elimination of flaky particles, as the flakiness index was 0% across all GPCA mixes, compared to 15.25% in natural aggregates. This observation aligns with pelletization studies that emphasize improved particle shape and reduced flaky fractions (**Bekkeri, 2023; Sunil et al., 2022**). However, the elongation index was significantly higher in GPCA (92–100%) than in natural aggregates (26%), indicating elongated particle shapes. Overall, the findings highlight that 6M molarity under ambient curing produces the most balanced aggregates, combining strength, density, and abrasion resistance, while 8M aggregates showed weaker performance due to excessive porosity and poor abrasion resistance (**Biswal & Dinakar, 2021; Naveena & Narayana, 2022**).

7. Sustainability Impact of GGBS Utilization

The use of GGBS aggregates addresses environmental challenges by reducing reliance on quarrying, which depletes resources and increases carbon emissions. Valorizing GGBS through pelletization supports circular economy principles and waste utilization (**Patra & Mukharjee, 2021; Biswal & Dinakar, 2021**).

Replacing natural aggregates with GGBS lowers CO_2 emissions, as quarrying and transport are energy-intensive, while pelletization repurposes industrial by-products. Studies show embodied carbon reductions of up to 40–50% depending on replacement levels (**Mallikarjun Rao et al., 2020; Naveena & Narayana, 2022**).

Pelletized aggregates also enhance durability and service life, reducing maintenance needs and lifecycle emissions, consistent with prior findings on synthetic aggregates (**Sunil et al., 2022; Bekkeri, 2023**).

8. Conclusion

This study demonstrated the feasibility of producing eco-friendly coarse aggregates using Ground Granulated Blast Furnace Slag (GGBS) and M-sand through pelletization. The 6M molarity mix under ambient curing conditions showed the most balanced performance in terms of strength and durability, consistent with prior findings on optimized GGBS aggregates (Ingale, Rathod, & Agarwal, 2021; Kurzekar et al., 2024). Beyond technical performance, the use of GGBS aggregates reduces reliance on natural quarrying and supports circular economy principles, aligning with sustainable construction practices (Patra & Mukharjee, 2021; Biswal & Dinakar, 2021). Overall, pelletized GGBS aggregates present a viable alternative to conventional coarse aggregates, offering both engineering and environmental benefits.

References

[1] Naveen, M. P., & Narayana, G. (2022). Manufacturing process of alkali activated coarse aggregate using pelletization technique. *Journal of Engineering Research*.

[2] Mallikarjun Rao, G., Anil Kumar, Y., Vengala, J., & Venu, M. (2022). Performance of fly ash and GGBS-based geopolymer concrete using single alkali activator solution and its cost analysis. *International Journal of Civil Engineering Research*.

[3] Bekkeri, G. B. (2023). Producing alkali activated artificial aggregates by pelletization of fly ash. *Materials in Civil Engineering Journal*.

[4] Ingale, N., Rathod, J., & Agarwal, P. (2021). Study on properties of concrete using GGBS. *International Journal of Innovative Research in Science, Engineering and Technology*.

[5] Sandeep, S. (2021). Effect of molarity on compressive strength of geopolymer mortar with GGBS and metakaolin. *Construction Materials Research Journal*.

[6] Singh, S., & Patel, S. (2020). Potential use of fly ash for developing angular shaped aggregate. *Journal of Sustainable Construction Materials*.

[7] Mallikarjun Rao, G., Anil Kumar, Y., Vengala, J., & Venu, M. (2020). Use of fly ash and GGBS as source materials for geopolymer production. *International Journal of Structural Engineering*.

[8] Biswal, U. S., & Dinakar, P. (2021). A mix design procedure for fly ash and ground granulated blast furnace slag-based treated recycled aggregate concrete. *Journal of Materials in Civil Engineering*.

[9] Kurzekar, A. S., Waghe, U., Ansari, K., Dabhade, A. N., Biswas, T., Algburi, S., Khan, M. A., Allthaqafi, E., Islam, S., & Palanisamy, J. (2024). Development and optimization of geopolymer-based artificial angular coarse aggregate using cut blade mechanism. *Construction and Building Materials*.

[10] Patra, R. K., & Mukharjee, B. B. (2021). Influence of incorporation of ground granulated blast furnace slag in concrete. *International Journal of Concrete Research*.

[11] Sunil, R., Megha, R., Vijayan, A. K., & Ramaswamy, K. P. (2022). Preparation and properties of alkali activated coarse aggregate using GGBS and fly ash. *Journal of Sustainable Construction Engineering*.