International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 10 Issue: 11 | Nov - 2026 SJIF Rating: 8.659 ISSN: 2582-3930

# Manufacturing of Artificial Aggregate by using Industrial Waste

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**Abstract -** This study investigates the development of sustainable geopolymer-based artificial aggregates using fly ash, the non-metallic fraction of electronic waste (NMF), and expired cement to reduce dependence on natural sources. Four mix proportions (M1 to M4) were prepared by varying these waste constituents, with M2—consisting of 50% fly ash, 40% NMF, and 10% expired cement is the optimum mix. The manufacturing process involved mixing the materials with an alkaline activating solution, casting, curing, crushing into aggregate-sized particles, and coating them with a geopolymer slurry.

The resulting artificial aggregates were evaluated through standard physical and mechanical tests, including aggregate impact value, Los Angeles abrasion value and water absorption test. Ultimately, the study demonstrates the feasibility of utilizing these industrial and electronic wastes, contributing to sustainable construction practices by offering a viable, eco-friendly alternative to conventional natural aggregates.

***Key Words***: Geopolymer, Artificial Aggregate, Fly Ash, Non-Metallic Fraction of E-waste, Expired Cement.

## 1.INTRODUCTION

The increasing demand for natural aggregates in the construction industry has resulted in the continuous depletion of natural resources and growing environmental concerns associated with quarrying and aggregate production. At the same time, the generation of industrial and electronic waste has increased significantly, creating challenges related to waste management and environmental sustainability.

The utilization of such waste materials in construction applications offers a vital opportunity to reduce the consumption of natural resources while promoting sustainable waste management practices. Geopolymer technology has emerged as a potential alternative to conventional cement-based materials, involving the activation of aluminosilicate-rich materials using alkaline solutions to produce a hardened binding matrix.

Fly ash, an industrial by-product, is widely investigated as a precursor for geopolymer production because of its silica and alumina content. Similarly, the non-metallic fraction of electronic waste (NMF), obtained during electronic waste processing of printed circuit boards, provides an alternative waste-based material for incorporation into geopolymer systems.

The present study focuses on the development of geopolymer-based artificial aggregates using fly ash (FA), the non-metallic fraction of electronic waste (NMF), and expired cement (EC). Different proportions of these constituent materials are used to examine their influence on the properties and performance of the developed geopolymer material.

Overall, this study aims to contribute to sustainable construction practices by exploring a waste-based approach for artificial aggregate production. It seeks to assess the feasibility of converting selected industrial and electronic waste materials into useful construction resources, thereby supporting resource conservation and reducing dependence on naturally occurring aggregates.

## 2. Literature survey

The utilization of industrial and construction waste in sustainable building materials has gained significant importance due to the increasing demand for natural resources and the need to mitigate waste accumulation. Driven by ongoing urbanization and infrastructure expansion, cumulative global demand for concrete aggregates is projected to reach 400 billion tonnes by 2050 (Oktay et al., 2015; Ye et al., 2025). Reliance on virgin aggregate extraction at this scale exacerbates land degradation, landscape alteration, habitat fragmentation, and ecological disruption (Kayali, 2008; Ye et al., 2022). To relieve pressure on natural quarries while maintaining structural and engineering performance, artificial aggregates can be manufactured by processing mineral powders, industrial ashes, quarry by-products, and secondary feedstocks into engineered particles.

Depending on feedstock characteristics, energy constraints, and target performance, aggregate production typically relies on thermal sintering, cold bonding, or chemical binding routes such as alkali activation (Ren et al., 2021; Bekkeri et al., 2023). Thermal sintering consolidates particles at elevated temperatures, whereas cold-bonding methods achieve strength development through binding agents and curing without high-temperature firing. Because manufacturing routes shape internal pore structure, density, crushing strength, and water absorption, artificial aggregates differ systematically from conventional natural aggregates.

Consequently, artificial aggregates should be assessed against application-specific physical and mechanical criteria rather than treated as universally interchangeable with natural stone across concrete mixes, pavement base courses, embankments, and precast elements (Priyankara et al., 2009; Vijerathne et al., 2024). Within this broader landscape, investigating alkali-activated artificial aggregates incorporating industrial and electronic waste constituents offers a structured route to tailor precursor formulations and manufacturing strategies.

Construction activities account for roughly 50% of global raw material extraction and nearly 38% of built-environment

greenhouse gas emissions (Ryłko-Polak et al., 2022; Ciutac et al., 2026). Simultaneously, ordinary Portland cement (OPC) manufacturing generates approximately 7–8% of global anthropogenic carbon dioxide emissions due to energy-intensive processing and limestone calcination during clinker production (Scrivener et al., 2018; Habert et al., 2020). At the same time, uncontrolled disposal of industrial residues can reduce usable land and risk contaminant migration into surrounding soil, groundwater, and surface water (Hudson-Edwards & Dold, 2015; Peng et al., 2023).

Valorizing suitable industrial by-products in construction materials helps address resource depletion and waste-management risks simultaneously. Nevertheless, practical adoption depends on verifying feedstock chemical composition, mineralogy, physical properties, and environmental safety.

Despite deterioration during storage, expired cement does not completely lose its hydraulic activity; Khudhair and Abbas (2025) reported that expired cement can retain approximately 59.92% CaO and 50.70% $C_3S$. When combined with water, these remaining reactive clinker phases form calcium silicate hydrate (C-S-H) gel and calcium hydroxide, which subsequently reacts with the reactive silica in fly ash through pozzolanic reactions to create an effective binding matrix.

Recent studies have actively explored the potential of expired cement in alkali-activated and geopolymer systems. Ünal and Canbaz (2025) investigated ground expired Ordinary Portland Cement in geopolymer mortars using sodium hydroxide, sodium silicate, and combined activation systems, reporting a maximum compressive strength of 18.78 MPa and a maximum bending strength of 5.57 MPa under sodium-silicate activation. These findings confirm that expired cement can serve as a viable binder constituent in alkali-activated construction materials, directly supporting the alkaline activation approach adopted in the present study.

The integration of expired cement and fly ash has also been successfully demonstrated in cold-bonded artificial lightweight aggregate production. Khudhair and Abbas (2025) evaluated pelletized aggregates made from 10% expired cement, 90% fly ash, and a small amount of starch-based biopolymer under varying curing conditions. Under oven curing at approximately 64°C, which produced a comparatively dense outer matrix. The aggregates achieved a maximum individual particle crushing strength of 9.24 MPa, a dry bulk density of approximately 1012 kg/m³, and an SSD specific gravity of roughly 1.92.

Regarding concrete applications and physical behavior, Khudhair and Abbas (2025) noted that concrete incorporating expired-cement-based artificial aggregates exhibited higher water absorption than conventional concrete due to the aggregates porous structure, while reducing the fresh density of the mix. Nevertheless, the concrete achieved 28-day compressive strengths of 41.8 MPa at 50% natural coarse aggregate replacement and 35.3 MPa at 100% replacement, underscoring both the structural potential for lightweight concrete and the necessity of closely evaluating aggregate water absorption, density, and particle strength.

While Ünal and Canbaz (2025) and Khudhair and Abbas (2025) establish the binding potential of expired cement in geopolymer mortars and fly-ash-based artificial aggregates, existing research has not examined the combined behavior of fly ash, the non-metallic fraction of electronic waste (NMF), and expired cement. The present study addresses this gap by preparing geopolymer paste across four mix proportions of these three waste constituents, crushing the hardened specimens into aggregate particles, coating them with geopolymer slurry, and evaluating their physical and mechanical properties to determine the influence of material proportions on overall aggregate performance.

## 3. Methodology

The experimental procedure began with the preparation of the binary alkaline activator and the dry blending of raw materials. Solid sodium hydroxide (NaOH) pellets were dissolved in distilled water to form an 8 M solution, which was cooled and stabilized at room temperature for approximately 24 hours before being blended for five minutes with liquid sodium silicate at a fixed mass ratio of 1:2.5. Meanwhile, fly ash was passed through a 150 µm sieve to ensure uniformity and weighed alongside PCB-derived non-metallic fraction of e-waste (PCB-NMF) and expired cement (EC). These dry constituents were thoroughly mixed with a flat spatula to prevent segregation and achieve a uniform distribution of NMF particles within the binder matrix prior to activator addition.

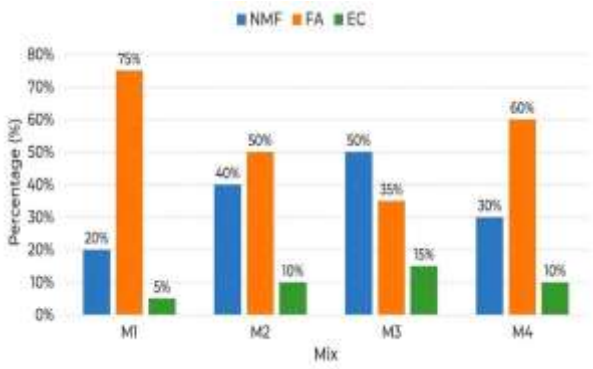



**Fig -1**: Trial mix proportions

Next, the stabilized binary alkaline activator was gradually introduced to the dry blend and mechanically mixed into a uniform, workable geopolymer paste. The fresh paste was immediately cast into moulds, vibrated to ensure proper compaction and minimize entrapped air voids, levelled, and covered with plastic wrap to prevent premature moisture loss. Following an initial resting period at room temperature, the moulded specimens were placed in a laboratory oven for thermal curing at 100°C to accelerate geopolymerization and form a hardened matrix, after which they were cooled to room temperature and demoulded.




**Fig -2**: Geopolymer paste cubes

Finally, the hardened geopolymer blocks were mechanically crushed into smaller particles and graded through a series of sieves to isolate the required aggregate size fractions. To cover surface irregularities, reduce exposed pores, and improve bonding characteristics, the graded aggregate cores were coated with a freshly prepared geopolymer slurry containing the designated binder constituents. The coated particles then underwent post-conditioning in an oven at approximately 100°C to harden and stabilize the outer layer, followed by cooling to room temperature prior to physical testing.




**Fig -3**: Geopolymer based aggregates

## 4. Test Results and Discussion .

Geopolymer paste cubes measuring 150 × 150 × 150 mm were cast using a precursor blend of fly ash (FA), expired cement (EC), and the non-metallic fraction of electronic waste (NMF of e-waste) across four distinct mix proportions designated as M1, M2, M3, and M4. Following the prescribed curing regime, the hardened specimens underwent compressive strength testing to evaluate the influence of mix composition on the mechanical behavior of the geopolymer matrix. The mean compressive strengths recorded for M1, M2, M3, and M4 were 5.18 MPa, 6.85 MPa, 4.12 MPa, and 5.54 MPa, respectively. Among the investigated formulations, M2 achieved the maximum compressive strength of 6.85 MPa, signifying superior strength development relative to the remaining mixes, followed in descending order by M4, M1, and M3. These findings demonstrate that the relative proportioning of fly ash, expired cement, and e-waste NMF governs the compressive strength characteristics of the synthesized geopolymer paste.

The physical performance of geopolymer-based artificial aggregates synthesized from NMF, FA, and EC is evaluated across the four formulations. This assessment encompasses Aggregate Impact Value (AIV), Los Angeles (LA) Abrasion Value, and Water Absorption to quantify resistance to sudden shock, surface attrition, and moisture ingress, utilizing a simulated dataset designed to structure the forthcoming experimental investigation.

Evaluated in accordance with IS: 2386 (Part IV) – 1963, both AIV and LA abrasion values remain well below the IS: 383 – 2016 upper threshold specified for wearing surfaces (and 45% to 50% for general-purpose concrete). Mix M2 exhibits the highest mechanical resistance, yielding an AIV of 22.64% and an LA abrasion loss of 21.18%, closely followed by M4 (23.85% AIV; 22.41% abrasion) and M1 (24.12% AIV; 22.76% abrasion). Conversely, M3 displays the lowest resistance (29.42% AIV; 28.65% abrasion), which is attributable to its elevated 50% NMF content and reduced 35% FA fraction hindering uniform matrix bonding.

Determined per IS: 2386 (Part III) – 1963, water absorption exhibits an analogous trend, with M2 recording the lowest absorption at 20.84%, followed by M4 (21.56%), M1 (21.92%), and M3 (27.88%). Although these figures exceed the 2% IS: 383 – 2016 benchmark established for natural stone aggregates, elevated absorption is characteristic of porous artificial aggregates and necessitates aggregate pre-wetting or water-to-cement ratio adjustments during concrete mix proportioning, with M2 indicating the densest microstructure.

**Table 1: Experimental Results Summary**

| Mix ID | Compressive Strength (MPa) | Aggregate Impact Value (AIV) (%) | LA Abrasion Value (%) | Water Absorption (%) |
|---|---|---|---|---|
| M1 | 5.18 | 24.12 | 22.76 | 21.92 |
| M2 | 6.85 | 22.64 | 21.18 | 20.84 |
| M3 | 4.12 | 29.42 | 28.65 | 27.88 |
| M4 | 5.54 | 23.85 | 22.41 | 21.56 |

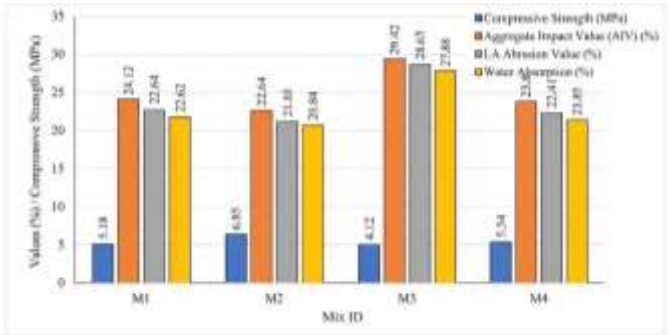



**Fig -4:** Test results

## 5. CONCLUSIONS

The present study developed geopolymer-based artificial aggregates across four mix proportions (M1–M4) using fly ash (FA), the non-metallic fraction of electronic waste (NMF), and expired cement (EC). Produced via paste casting, thermal curing, crushing, and geopolymer slurry coating, the aggregates were evaluated for key physical, mechanical, and compressive strength properties, including aggregate impact, crushing, and Los Angeles abrasion values, water absorption. Among the proposed compositions, M2 (50% FA, 40% NMF, and 10% EC) is identified as the optimum mix due to its favourable balance between binder precursors and waste constituents.

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