A Comprehensive Review On Lithium Slag Waste as a Construction Material

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Abstract :

Purpose : “Lithium Slag Waste(LSW)," presents opportunities as well as challenges for the global construction sector. The purpose of this work is to provide a thorough literature evaluation of LSW in concrete construction materials.
Design/Methodology/Approach : This study examines 4,122 Scopus publications to look at how waste is generated in various nations and creative ways to incorporate LSW into construction as a sustainable approach. Famous researchers and their networks of collaboration are listed in this study, which shows a healthy and active field with an increase in research output, particularly from 2018 to 2022.VOS Viewer is used to visualize data in order to display trends, patterns, and research interests over time.
Findings : These Findings suggest that LSW can enhance the mechanical properties and sustainability of building materials.The inconsistent findings indicate that more optimization is needed. Scientific attention has been drawn to LSW in building because of its effects on the environment, life cycle, and economy. The field holds immense promise for enhancing the use of LSW materials, creating advanced prediction models, researching environmental consequences, economic analysis, policy formation, innovative construction techniques, international collaboration, and public awareness. LSW can be utilized in sustainable building, according to this study. It emphasizes how much research and innovation are needed in this field. The use of electronic waste in buildings is made possible by this, which supports environmental sustainability and a circular economy.

Reasearch Limitations/Expectations : The Findings highlight how important it is to continue researching and developing new ways to use LSW for sustainable building techniques. This study establishes the foundation for incorporating LSW into building, promoting environmental sustainability and a circular economy.

Social implications : The social ramifications of incorporating LSW in into construction are note worthy.By generating new jobs in the recycling and building industries, LSW not only solves environmental issues but also advances social sustainability. It promotes social responsibility and

awareness for trash management and sustainable methods. Furthermore, by cutting construction costs, this strategy can increase accessibility to development projects and possibly lower home prices.

Originality/Value : This research contributes to the field by offering a comprehensive assessment of LSW in concrete construction materials, highlighting its global significance.

Keywords :LSW, Constructio nmaterials, Sustainability, ,Concrete, Global waste management , Environmental impact.

Paper Type : Literature Review.

1. **Introduction** : The 5% of alkali activators and 25% of slag/silica ratio was most effective ratios inthe geopolymer concrete and addition of superplasticizer reduced the water requirement in the concrete and improves the workability (Sayed, 2018). It was found that slag pastes have less porosity and compressive strength was better when specimens cured in autoclave. It was identified that autoclaved specimens produce calcium silicate hydrates and tobermorite gel has a main hydration (Rashad et al, 2018). The effect of oven curing of specimen results the better compressive strength. The slag aggregates and addition of slag in the flyash attain the higher compressive strength at early age (Bagheri and Nazari, 2020). The addition of AASC fibre in the concrete reduces the compressive strength but large improvement observed in the splitting tensile and flexural strengths of the concrete (Bernal et al, 2020).

The durability properties like carbonation resistance, water sorption and permeability properties are also improved at higher binder contents with AASC fibre (Bernal et al, 2011). The slag/metakaolin blends with higher concentration of alkali activatorsshows the higher compressive and flexural strength similarly it reduced water sorptivity and lower chloride permeability (RCPT) (Bernal, 2022).

The presence of aluminosilicate gel in the slag accelerated the carbonation is highly polymerised and decalcification mechanism also consistent. When flyash and slag blends it forms (C–A–S–H and N–A–S–H). This delivers the better durabilityproperty of geopolymer concrete (Bernal, 2022). The role of Ca in the slag leads to hydration process metakaolin has the higher surface area and small particle shape. This requires the high water content and higher drying shrinkage in concrete.

The geopolymer concreter specimen cured in the saline water shows the better strength and the microstructural studies like scanning electron microscopy, Energy- dispersive X-ray spectroscopy and X-ray diffraction were also shoes the very lesser sorptivity in the concrete (Giasuddin et al, 2023). The presence of Sodium hydroxide and sodium silicate improves the bulk density and compressive strength in the slag based geopolymer concrete. Sulphate resistance of the concrete was higher by observing the samples immersed in the sea water for 6 months (El-Didamony, 2022). Addition of Cu–Ni in the slag results in better geopolymerisation reaction in concrete improvedthe compressivestrength(Kalinkinetal,2022).ThestudiedCa$(OH)_2$-based

GGBS concrete enhanced workabilityby low slump value and improved rate of compressive strength by W/B ratio in geopolymer concrete.

The investigation shows Ca$(OH)_2$-based GGBS concrete has a substantial potential when theW/Bratio is owerthan30%in concrete (Yanget al, 2022). The studyshows inorganic polymers are synthesised from low-Ca electric arc ferronickel slag. The result of experimental conditions on the compressive strength of the final products is evaluated. The consumption ofcertain potentiallyhazardousmining and metallurgical wastes headed for an increased sustainabilityofthewiderminerals area (Komnitsas et al, 2019). In the slag setting time NaOH concentration increases the setting time decreases, 15 to 20% of the total weight of binder were used as the concentration of alkali activators to achieve the high compressive strength in room temperature itself (Lee and Lee, 2023).

This leaves a substantialquantity of 44.3 million metric tonnes with an uncertain environmental consequence. The economic worth of electronic LSW,which isapproximated atUS$94.4bn,standsinstark contrasttothehandlingof83%ofe-wastebyCO2-equivalent refrigerants, thus giving rise to detrimental practices(Murthyand Ramakrishna, 2022). The aforementioned activities encompass the discharge of 98 million metric tonnes of untreated CO2-equivalent refrigerants, the emission of 71 thousand metric tonnes of brominated flame retardants, and the dispersal of 50,000 metric tonnes of mercury (Zaragoza-Benzalet al., 2023). The total quantity of LSW being transported across borders is around 5.1 millionmetric tonnes. This includes both regulated movements, accounting for 1.8 million metric tonnes, and unregulated movements, accountingfor3.3millionmetrictonnes(Alabiet al.,2021). These transboundary movements pose difficulties in differentiating between lawful and unlawful operations. The need for international collaboration and the implementation of efficient policies cannot be overstated when it comes to tackling the environmental and health hazards linked to the improper handling of electronic trash, all while harnessing its significant economic opportunities (Turaga et al., 2019).

Quantitative measurement :

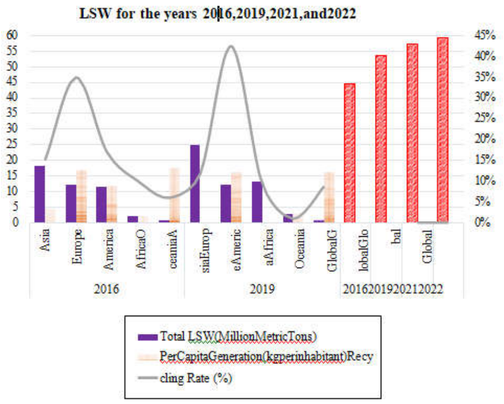
The fast growing worldwide waste stream, commonly referred to as LSW, is posing a serious environmental challenge. A substantial amount of electronic waste—44.7 million tonnes—was produced globally in the second year in metric tons. The weight of eight 4,500-ton Eiffel Towers is equivalent to this quantity of LSW (Baldeetal., 2017).This e-waste accumulation, which the Unitmetric Tonnes called a "tsunami" in 2018, is noteworthy since it is expected to exceed 50 million tonnes annually. The stream in question not only raises substantial environmental concerns but also has huge economic opportunities, anticipated to beat

$62.5 billion yearly (Ministry of Environment, 2019; Boletal). A number of variables, such as the rapid advancement of technology, modifications to media formats, significant price reductions, and intentional obsolescence, are contributing to the rise in electronic waste (Ghulam and Abushammala, 2023). In addition to investigating workable technological solutions, it is essential to create a thorough legal framework and put good logistics in place in order to adequately handle the problem of LSW.
The longevity of electronic components varies because, whereas display devices are frequently replaced regardless of their functioning state, CPUs are prone to becoming obsolete due to software advancements. According to production data, it is noteworthy that the United States and Europe are expected to contribute significantly to the annual LSW prediction of 50 million tonnes (Dwivedi et al., 2022). Remarkably, only a small percentage—between 15% and 25%—go through the recycling process, with the bulk being disposed of in inland landfills (Lange, 2021). A comparable estimate of the amount of electronic garbage, or "LSW," was made based on the United Nations data from 2006 (Bhutta et al., 2011). Furthermore, estimates for nations like India suggest a 500% increase over the next ten years. In terms of LSW generation, the USA leads the world, closely followed by China. despite the implementation of import limits, the following is a key destination for disposal (Boardman et al., 2020). Technology, especially mobile phones, are pervasive and greatly increasing the production of LSW. Unfortunately, these outdated electrical devices—which contain precious metals like copper, gold, and silver—are purposefully made to last shorter periods of time, which encourages users to replace them more frequently. Unfortunately, it has been noted that outdated electronic gadgets are responsible for more than 70% of the heavy metals discovered in US landfills (Ari, 2016). Despite being well known, the trajectory of electronic garbage has generated debates over its relative risks to other waste types and the possible repercussions of controlling the flow of used electronics (Santhanam Needhidasa et al., 2014). Restricting this commerce, according to others, can have unforeseen effects on the supply chain.

LSW Data

Around 59.4 million tonnes of LSW were produced worldwide in 2022, meaning that there was a total of over 347 million tonnes of unrecycled LSW worldwide, as illustrated in Figure 2.It is crucial to recognize that in 2019, an estimated 5.1 million tonnes of LSW, or slightly less than 10% of all LSW worldwide, were transported over international boundaries, despite the lack of comprehensive data addressing transboundary LSW movements in 2022. There are two categories for the transboundary movement of LSW: 3.3 million tonnes are transferred under uncontrolled conditions, and 1.8 million tonnes are transported under regulated conditions. This distinction highlights the need for better LSW management and regulation in order to reduce the risks associated with inappropriate handling and disposal (Statista, 2023,2023,2020).

Figure2Globalproduction of LSW



Recycling Benefits

The most efficacious strategy for addressing the issue of LSW is to engage in the recycling of EOL equipment. These gadgets possess valuable materials, such as metals, that may be recycled, promoting resource conservation and pollution reduction. Moreover, the act of recycling serves to reduce the production of greenhouse gases that result from the manufacturing of new products(Seifetal.,2023).Numerous components derived from electronic trash, including ferrous and non-ferrousmetals, glass, and diverse polymers, possess the potential to undergo recycling processes and thereafter be repurposed. Certain 3D printers have been specifically engineered to generate recyclable waste, thereby mitigating the adverse impact of atmospheric pollution (Bahadoranet al.,2022). Responsible recycling procedures place a high emphasison safeguarding the well-being of both humans and the environment,with a focus one ensuring safety at both local and global levels. In Europe, there exists a system of incentives that encourages the repatriation of recycled metals to their respective source firms. Conversely, Japan's recycling system focuses on fostering sustainable product design and enables manufacturers to engage in the sale of recycled metals. The mismanagement of LSW results in the depletion of important resources, such as gold,which is found in far higher concentrations in LSW compared to gold ore.

2. LSW Analysis Data

LSW generation is a growing concern in contemporary society. The data presented above elucidates the trend in e-waste generation, measured in million metric tonnes, spanning from 2019to2030, as shown in Figure3.

Figure3 reveals a steady increase in the amount of electronic waste overtime. The data indicates a discerniblerising trajectory, commencing from a baseline of 53.6 million metric tonnes in 2019. The generation of LSW experienced a significant increase ,reaching a total of 65.3million metrictonnes by the year 2023. Based on projections, it is anticipated that the quantity will escalate to a concerning74.7 millionmetrictonnes by the year2030. It is apparent that there was a marginal increase of 1.9 million metric tonnes between the years2019and2020. In the following years ,there were more noticeable increases.

The period from 2022 to 2023 saw a notable increase of 2 million metric tonnes. The research findings additionally demonstrate a consistent and upward trajectory, where in the annual increase normally exhibits an upward trend, except for a slight decline in the year-on-year rise recorded between 2028 and2029(Statista,2023,2023,2020).The persistent increase in the generation of LSW can be ascribed to a multitude of factors. The rapid progression of technology, resulting in the swift obsolescence of electronic devices, together with the expanding culture of consumption, may serve as noteworthy factors. Additionally, the available data lacks a comprehensive categorization of LSW according to kind, hence limiting the ability to gain a more nuanced comprehension of the various electronic devices that contribute to this waste stream. The aforementioned upward trajectory further emphasizes the necessity for sustainable methods of managing LSW. It is advisable to explore implementing strategies such as enhanced recycling techniques, extended producer responsibility, and consumer awareness campaigns.

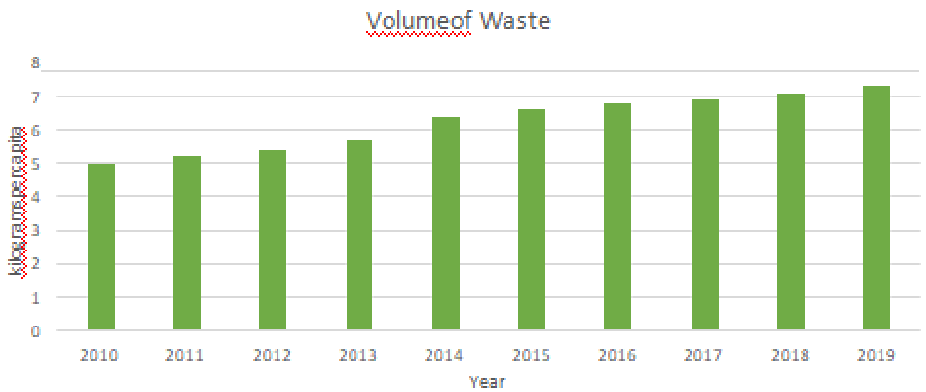
Per capita LSW generation

The statistic illustrates the annual per capita garbage generation in kilos from 2010to2019, as shown inFigure4. The data set provides valuable insights into the temporal volution of waste generation patterns with in a given population over the course of the last decade. The data indicates a progressive rise in waste production per individual throughout the specified timeframe. The annual garbage production per individual was 5kgin2010, and this figure experienced a gradual rise, culminating in a per capita waste generation of 7.3kgin2019.The data presented above illustrates the escalating trends in consumption and the prospective implications for increased manufacture of disposable goods, hence contributing to heightened waste generation. The increase in garbage generation has significant ramifications for waste management and efforts towards environmental sustainability (Statista, 2023, 2023, 2020). The aforementioned statement emphasizes the significance of implementing sustainable waste reduction and recycling strategies to efficiently handle the growing volume of waste and mitigate its adverse effects on the environment.

Figure3e-lsw generations over the time

Source: Self-created

Figure4Volumeof LSW generated in previousyear



Source: Self-created

2. LITERATURE REVIEW

Research studies in the past had shown that fly ash-based geopolymer has emerged as a promising new cement alternative in the field of construction materials. The term geopolymer was first coined and invented by Davidovits (1989). This was obtained from fly ash as a result of geopolymerisation reaction. This was produced by the chemical reaction of aluminosilicate oxides (Si_2O_5, Al_2O_2) with alkali polysilicates yieldingpolymericSi–O–Albonds.HardjitoandRangan (2005)demonstratedintheir extensive studies that geopolymer based concrete showed good mechanical properties as compared to conventional cement concrete. A comprehensive analysis on the various works done in geopolymer concrete is listed in Table 2.1.

The geopolymer can be produced with the basic raw materials containing silica and alumina rich mineral composition. Several studies have reported the use of the beneficial utilization of these materials in concrete. Most of the studies investigated the use of alkali activators containing sodium hydroxide and sodium silicate or a potassium hydroxide and potassium silicate. Cheng and Chiu (2003) reported the production of geopolymer concrete using slag and metakaolin with potassium hydroxide and sodium silicate as alkaline medium.

Palomo et al (1999) produced geopolymers using fly ash with sodium hydroxide and sodium silicate as well as with potassium hydroxide with potassium silicate combinations. The results from the studies exhibited an excellent formation of geopolymer with rapid setting properties. It can be noted that the presence of calcium content in fly ash played a significant role in compressive strength development (Van Jaarsveld et al, 2003). The presence of calcium ions provides a faster reactivity and thus yields good hardening of geopolymer in shorter curing time.

The geopolymer based concrete received a wider acceptance among manyresearchers and can be a prospective application in future construction. The production of this material is cost effective and environment friendly as it is produced primarily fromthe industrial waste. The considerable research towards its potential use as a concreting material has led to the production of geopolymer concrete (Davidovits, 1989). Synthesis of different geopolymer derivatives was found to be dependent on any silicate rich source material such as fly ash, furnace slag, bentonite, metakaolin, and rice husk ash. Like cement concrete, geopolymer based cementitious material is also ahighlybrittlematerial which exhibits poortensileproperties.This necessitates a comprehensive investigation to be conducted for improving the tensile properties of geopolymer concrete.

Fibre addition in brittle cementitious matrix is a well-known technique to improve the toughness properties of the composite. Fibres are typically a discrete reinforcement mechanism used in either cement concrete or a geopolymer based concrete in order to provide adequate bending resistance (Pereira et al, 2006). The binder generally usedin geopolymer concrete consisted of either slag or fly ash based system. Since fly ash and furnace slag is produced in large quantity as a waste from industry and needs tobe disposed safely.

This inevitably finds a potential alternative to be used as a construction materialwhich can consume a large quantity (Gokulram et al, 2013). Good toughening characteristics and crack resistance of geopolymer concrete can be achieved with the addition of discrete fibre leading to good matrix strengthening and reduced crack deflection properties. The matrix densification and fibre matrix interface can providea higher load carrying capacity of geopolymer concrete depending upon the stiffness of the fibres.

The steel fibres addition in geopolymer based cementitious composites provides post- crack ductility even upon repeated loading cycles (Vijai K et al, 2012). Even though there exist several advantages of geopolymer based concrete, the poor toughness characteristic is the negative effect which restricts the wider applications. Different typesofshortfibreinclusionswerealsoinvestigatedingeopolymerconcretewithslag basedbinder.Theresultsdemonstratedthatthefibreadditionprovidedadequate flexural strength enhancement and toughness to provide stability in the failure mode (Ng et al, 2010; Deepa Raj et al, 2013; Natali et al, 2011).

Limited studies investigated the reinforcing efficiency in geopolymer concrete and lack a systematic evaluation on its flexural performance. It is also understood from previous studies that the incorporation of fibres in geopolymer based concrete provided additional matrix strengthening leading to higher tensile performance provided with strain softening properties (Sarker et al, 2013). Compared to normal geopolymer concrete specimens fibre reinforced geopolymer concrete specimens are knowntoprovidelongtermdurabilityintermsof lowerwaterabsorptionandchloride penetration. This could be anticipated due to the crack bridging properties of thefibres in geopolymer concrete as a result of fibres stretchingthe crack openingaround the cracks (Shaikh, 2013).

Several studies reported that curing regime of geopolymer based concrete specimens requires a typical high temperature curing leading to faster geopolymer reactions and in this case of normal cured geopolymer specimens the activation energy can be provided with higher alkali concentration compared to lower level concentration (Moser et al, 2013). It was reported that fibre addition had shown a reduction in strength gain in early ages; however upon subsequent hardening the matrix strengthening provided higher composite strength (Shaikh, 2013).

Flexural strength gain in geopolymer concrete showed higher bending strengthleading to higher toughness. In another study it was reported that incorporation ofsteel fibres provided good toughening mechanism with the increased volume fraction of steel fibres up to 0.7%. (Sakulich, 2011; Bernal et al, 2006; Bernal et al, 2010; Bernal et al, 2012). Also, a reasonable increase in compressive, split tensile and flexural properties was anticipated with the increase in volume fraction of steel fibres (Yunsheng et al, 2008).

It is understood from the earlier studies that more appropriate method is required for characterizing the toughness properties of geopolymer concrete. In addition, the effects of activators on the strength enhancement and the rate of hardening properties under different high temperature curing need special attention.

GEOPOLYMERCEMENT (GPC)

Polymerization reaction is best observed in the presence of alkaline medium such as sodium hydroxide, or potassium hydroxide and the addition of silicates can be additional ionic composition with good bonding effects. The reactants in the chain reactioncanbe accelerateddduetohigher molarconcentrationof alkaliions; however, the increase in the concentration leads to rapid loss in consistency during mixing attributed to faster polymer reaction. The inclusion of sodium silicate in sodium hydroxide solution provides higher silicate content and due to which the gelformation is likely to provide faster polymerization. A similar reaction is observed in the case of potassium silicate added to potassium hydroxide solution. It is known that the conventional organic polymerization involves the formation of monomers in a given solution in which the reaction can be made faster to polymerize and form a solid polymer.

The geopolymerization process involves three separate processes and during initial mixing, the alkalinesolution dissolvessiliconand aluminium ions in therawmaterial (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 neighbors condense to form an oxygen bond linkingthe water molecule, and it is seen that each oxygen bond is formed as a result of a condensation reaction and thereby bonds the neighboring Si or Al tetrahedra. A clear representation of the chain reaction involved during the polymerization with a fundamental understanding from the literature.

UTILIZATION OF LSW IN GEOPOLYMERCONCRETE

Polymerization reaction is best observed in the presence of alkaline medium such as sodium hydroxide, or potassium hydroxide and the addition of silicates can be additional ionic composition with good bonding effects. The reactants in the chain reaction can be accelerated due to higher molar concentration of alkali ions; however, the increase in the concentration leads to rapid loss in consistency during mixing attributed to faster polymer reaction. The inclusion of sodium silicate in sodium hydroxide solution provides higher silicate content and due to which the gel formation is likely to provide faster polymerization.

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Polymers are sensitive towards heat and can form a stronger chain due to polycondensation. It is noted from the basic chemical reaction when subjected to heat causes silicon and aluminium hydroxide molecules to polycondense or polymerize, to form rigid chains or nets of oxygen bonded tetrahedra. Also, at higher elevated temperatures it produces stronger geopolymers. Aluminium ions require metallic Na+ ions for charge in balance. Davidovits and Davidovics (1988) reported that geopolymers can harden rapidly at room temperature and can gain the compressive strength up to 20MPa in 1 day. Comrie et al (1988) conducted tests on geopolymer mortars and reported that most of the 28 day strength was gained during the first 2 days of curing. The geopolymer cement is found out to be acid resistant, because, unlikethePortlandcement,geopolymer cements do not depend onlime and are not dissolved by acidic solutions. Most of the studies concluded that the concentration of NaOH solution plays the most important role on the strength of the fly ash based geopolymers.

The addition of calciumoxide along with sodium hydroxide accelerates the geopolymerisationinflyash.Guoetal(2010)conductedexperimentalstudiesinclass C fly ash-based geopolymers using a mixed alkali activator of sodium hydroxide and sodium silicate solution. It was reported that a high compressive strength can be obtained when the molar ratio of silicate to sodium is 1.5, and the mass proportion of Na_2O to LSW was 10%. The compressive strength of these samples was around 63MPa when it was cured at 75°C for 8h followed by curing at 23°C for 28 days. Low-calcium fly ash is preferred than high calcium (ASTM class C) LSW for the formation of geopolymers, since the presence of calcium in high amount may affect the polymerization process (Gourley, 2003).

The suitability of different types of fly ash can be a potential source for studying the type and efficiency of geopolymerization reaction. It was also reported that geopolymerisation reaction can be effective in low calcium LSW depending on if it contains unburnt carbon less than 5% and 10% CaO content, reactive silica about 40– 50%, and particles finer than 45microns (Fernández-Jiménez and Palomo,2003; Van Jaarsveld et al, 2003). That LSW with higher amount of CaO produced higher compressive strength, due to the formation of calcium-aluminate hydrate and other calcium compounds, especially in the early ages.

The most preferred alkaline solution used in geopolymerisation is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate. Palomo et al, (1999) reported that reactions occur at a high rate when the alkaline liquid contains soluble silicate, either sodium or potassium silicate, compared to the use of only alkaline hydroxides. Xu and Van Deventer (2000) confirmed that the addition of sodium silicate solution to the sodium hydroxide solution as the alkaline liquid enhanced the reaction with fly ash. Furthermore, geopolymerisation with the NaOH solution resulted in higher dissolution of minerals than KOH solution.

A combination of sodium hydroxide and sodium silicate solution, after curing the specimens for 24 hours at 65°C, provided higher strength (Xu and Van Deventer, 2002). It was reported that the proportion of alkaline solution to aluminosilicate powder by mass should be approximately 0.33 to allow the geopolymeric reactions to

occur. Alkaline solutions formed a thick gel instantaneously upon mixing with the aluminosilicate powder. The previous studies also reported that mixtures with high water content, that is, H_2O/Na_2O = 25, developed very low compressive strengths. Palomo et al (1999) reported that curing temperature is an important indicator for strength gain in LSW-based geopolymers and improves the mechanical strength. Higher curing temperature and optimum curing time were found to influence the compressive strength gain in geopolymer concrete. Alkaline liquid that contained soluble silicates was proved to increase the rate of reaction compared to alkaline solutions that contained only hydroxide.

STRENGTH DEVELOPMENT OF SLAG BASED GEOPOLYME CONCRETE

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LITERATURE REVIEW ON SLAG BASED GEOPOLYMER CONCRETE PROPERTIES

A low ratio of Ca/Si~0.3 in Alkali Activated Slag was the significance of coexistence of C–

S–H (I) gel and silica gel. Throughout decalcification of Alkali Activated Slag almost ample leaching of sodium and tetrahedral aluminum from C–S–H (I) gel also took place. Alkali Activated Slag showed considerably higher resistance to decalcification in relation to the standard CEM II due to the lack of portlandite, high level of geopolymerisation of silicate chains, low level of aluminum for silicon exchange in the structure of C–S–H (I), and the creation of protective layer of polymerized silica gel throughout decalcification process (Komljenović et al, 2012). The Scanning Electron Microscope coupled with Energy dispersive spectroscopy (SEM + EDS) contribution on H_2O/Na_2O MRs analysis for microstructural morphology to the product nature, compactness, and the reactivity of Ca^{2+} and Al^{3+} while Fourier transform infra-red (FTIR) spectroscopyindicates that H_2O/Na_2O ratios donated to the creation amorphousity and carbonation development but sparingly affected its formed polymerized structural units (SiQn(mAl), n = 2 and 3 (Yusuf, 2014).

The specimens with variable compositional ratios was synthesised from a blend of ladle slag and metakaolin or ladle slag and fly ash. Ambient cured alkali-activated materialsofcompressivestrengthsrangingbetween11and46MPawereattained.

Samples which are under temperatures up to 1000°C and investigated for residual strength, thermal expansion, and phase and microstructural changes (Murri, 2013). The influence of slag is found to be likelysame to that of the granulated blast furnace slag. A try has been made to correlate the reaction in C–S–H gel, structure and properties. It is found that slag, which is generated by a different method of iron making, provides the related kind of outcome as granulated blast furnace slag in fly ash based geopolymer (Nath and Sanjay Kumar, 2013).

The mostly amorphous geopolymer cured under ambient conditions transmits to the crystalline phases start when the mixture is cured at high temperature, and zeolitic precursor creates in sodium based high alkaline environment can be considered as a disordered form of the basic structure unit of the ABC-6 group of zeolites which containspoly-typesforexamplehydroxycancrinite,hydroxysodaliteand chabazite-Na (Oh et al, 2010). The concrete activated with Na_2CO_3 had insignificant tensile strengths after 1 day, increasing to ~2.5 MPa after 28 day. The key strengthening phasewasshown tobe calcium–silicate–hydrates inallformulae; thoseactivatedwith Na_2CO_3 also showed the presence of hydrotalcite. The concrete activated withNa_2CO_3 also exhibited the occurrence of hydrotalcite. No sign of geopolymeric segmentswasoriginated, thoughcombinationofsodiumtoformN–S–Hthatbalances charges arising from Aluminium replacement of Si in C–S–H is possible. Despite the short (~120 s) pot life of the sturdiest formula, NaCl was shown to be an active retarding agent, who decreases the strengths of different formulae, at poorest, by less than25%after28dayof curing (Sakulichetal,2009).Alumino–silicate–hydrate(A– S–H) and calcium–silicate–hydrate (C–S–H) gels with changing Si/Al and Ca/Si ratio are create to be the main reaction products. Co-occurrence of A–S–H and C–S–H gel supplementary indicates the interaction of fly ash and GBFS during geopolymerisation. Effort has been made to transmit the microstructure with the properties of the geopolymers (Kumar et al, 2010).

The two kinetic models are used to extract the significant parameters of the activation reaction. The temperature rise within the studied range impacts the total heat released bythe flyash rich pastes more than those of slag pastes. For the fly ash rich blends, it is exposed using the Knudsen rate constant that higher reaction temperatures are essential to extract realistic model-based kinetic parameters (Chithiraputhiran et al, 2013). The physical and mechanical properties of the geopolymer also interrelated wellwiththeconcentrationofalkalineactivatorsolutionandthequantityof

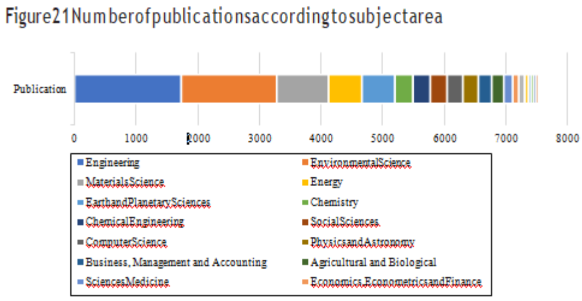
metakaolinite that is additional. The maximum compressive strength attained was 79MPa. For fire resistance tests, a 10 mm thick geopolymer panel was open to an 1100°C flame, with the measured reverse-side temperatures getting less than 350°C after 35 min (Cheng et al, 2003). The mesoporous characteristic of AGBFSCM was helpful to enhancement of separation productivity of photogenerated electron–hole pairs; whereas the yield of hydrogen construction can be enhanced by natural oxide semiconductors of Fe_2O_3 and TiO_2 as active type of catalyst existed in AGBFSCM matrix (Zhang et al, 2014).

Biblographic analysis

According to subject-area analysis

The distribution of research output across academic domains is explained in Figure 21.Descriptive analysis: With 1,733 publications, engineering has the most. Rapid technological advancements and a broad range of applications could fuel this field's intense research activity. Closely behind, Environmental Science has 1,549 articles. This high figure demonstrates the increased attention being paid to environmental issues such as climate change and sustainability.This area has undergone a lot of research because environmental challenges are urgent.With 841 articles, Materials Science comes in third. The topic is essential because of new materials that serve a variety of industrial and technological objectives. Chemistry has 293 publications, Earth and Planetary Sciences has 539, and Energy has 539.These figures highlight breakthroughs in chemical processes, products, planetary research, and sustainable energy. There are 250–300 papers in the fields of physics, astronomy, computer science, social sciences, and chemical engineering. Despite being fewer than the top subjects, these figures nonetheless reflect important research. There are 146–217 publications in the fields of business, management and accounting, agriculture and biological sciences, and medicine. These figures show a moderate level of research in these fields.

Figure 20: Categorization by academic or research departments



Source: Self-created

Mathematics, Decision Sciences, Arts and Humanities and Multidisciplinaryhave 39to61publications near the bottom of the list. Neuroscience, Psychology, Veterinary, Dentistry and Nursing have the fewest articles–less than five. These subjects have low counts, suggesting narrow research interests or little data for this data set. In conclusion, the distribution of publications across different subject areas reveals research trends and focus. Engineering and Environmental Science top the list, but study spans several fields, showing academic inquiry'scomplexity.

According citation analysis

Table3 provides a thorough summary of research papers and their corresponding citation counts over different years, categorized by several subject areas. The initial section labeled "An examination of the utilization of recycled aggregate in concrete applications from 2000 to 2017"comprises a cumulative count of 625references, with a not able quantity of publications spanning the years 2019 to 2023. Likewise, the second row, which centers on the research paper titled "Recycling of WEEEs: An economic assessment of present and future LSW streams", demonstrates a cumulative citation count of 538, indicating as ignificant impact on the academic domain. Furthermore,the row labeled"Utilization of silica gel or polyurethane immobilized bacteria for the purpose of self- healing concrete" demonstrates a citation count of 524, underscoring its notable significance. The table provides supplementary information on various studies, including "Thermochemical conversion of sewage sludge: A critical review" with 342 citations and"CO2 capture by accelerated carbonation of alkaline wastes: Are view on its principles and applications"with 306 citations. These studies highlight the wide range of research topics and their respective influences within their domains.

Figure 22shows the evolution of CiteScore for various publications throughout time. It began its run with Materials Today: Proceedings, which had a CiteScore of 0.4 in 2016 and increased to 3.2 by 2022. Between 2011 and 2022, Waste Management increased from 5.1 to 15.1 in popularity. Similar tothis,thecategoryConstructionand Building Materials sawan increase in score, going from 3.3 in 2011 to 12.4 in 2022. The numberofissuesintheJournalofCleanerProductionincreased from 5.1 in 2011 to 18.5 in 2022. Last, the number of issues in Sustainability rose from 1.4 in 2011 to 5.8 by 2022. The rising scores highlight the continued importance and influence of these publications in their industries.

Figure23showshowsourcecitationshavechangedover

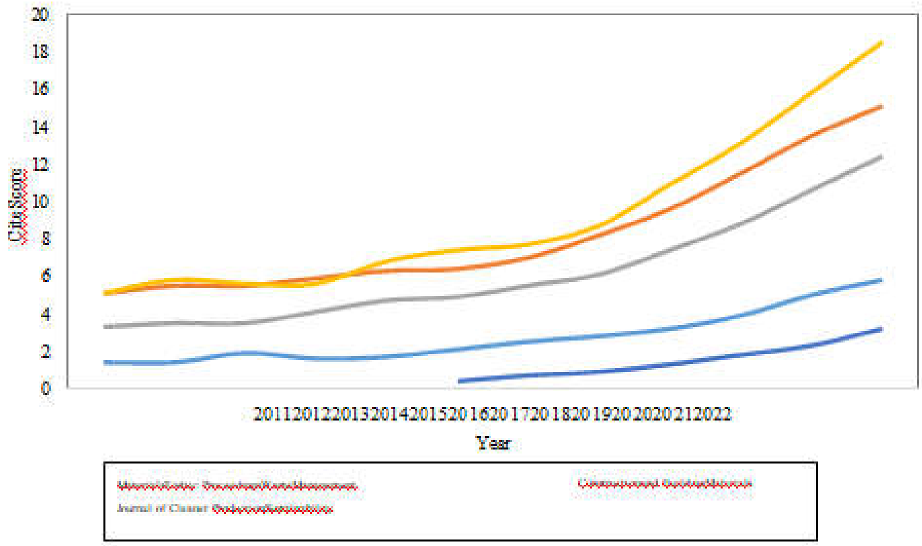
time for various publications by year. Citations for Materials Today: Proceedings began with one entry in 2009 and significantly increased to 64,935 by 2023. Starting at 295 in 1996, Waste Management grew to50,932by2023. With just 26 citationsin1996,Construction and Building Materials quickly grew to an astounding 216,012 by 2023. The number of citations in the Journal of Cleaner Production increased from30 in 1996 to 311,983 in 2023. Last but not least, Sustainability, which had just one citation in 2001, rose dramatically to 214,447 by 2023. This information highlights how these sources'standing and impact have grown over time in both academia and business.

Table3Summary of citations and publications in top ten documents

Check/ selectrow	Documents	Citations	<2019	2019	2020	2021	2022	2023	Subtotal	>2023	Total
1	Areviewofrecycledaggregateinconcrete applications(2000–2017)	2018	3	51	128	147	163	132	*621*	1	*625*
2	RecyclingofWEEEs:aneconomicassessmentof presentandfuturee-wastestreams	2015	159	84	78	96	61	60	*379*		*538*
3	Useofsilicagelorpolyurethaneimmobilized bacteriaforself-healingconcrete	2012	173	68	73	73	76	61	*351*		*524*
4	Thermochemicalconversionofsewagesludge:a criticalreview	2020			14	87	117	123	*341*	1	*342*
5	Fiber-reinforcedasphalt-concrete-Areview	2010	123	34	50	32	50	39	*205*		*328*
6	EffectsofcombinedusageofGGBSandflyash onworkabilityandmechanicalpropertiesof alkaliactivatedgeopolymerconcretewith recycledaggregate	2019		27	48	69	87	78	*309*		*309*
7	CO2capturebyacceleratedcarbonationof alkalinewastes:Areviewonitsprinciplesand applications	2012	134	26	34	35	49	28	*172*		*306*
8	Chapter2:Biochemistry,Physiologyand BiotechnologyofSulfate-ReducingBacteria	2009	177	17	25	30	29	21	*122*	1	*300*
9	Aninvestigationontheuseofshreddedwaste PETbottlesasaggregateinlightweightconcrete	2010	109	18	27	37	44	31	*157*		*266*
10	Hierarchicallystructuredzeolites:fromdesignto application	2020			2	51	110	97	*260*	1	*26*

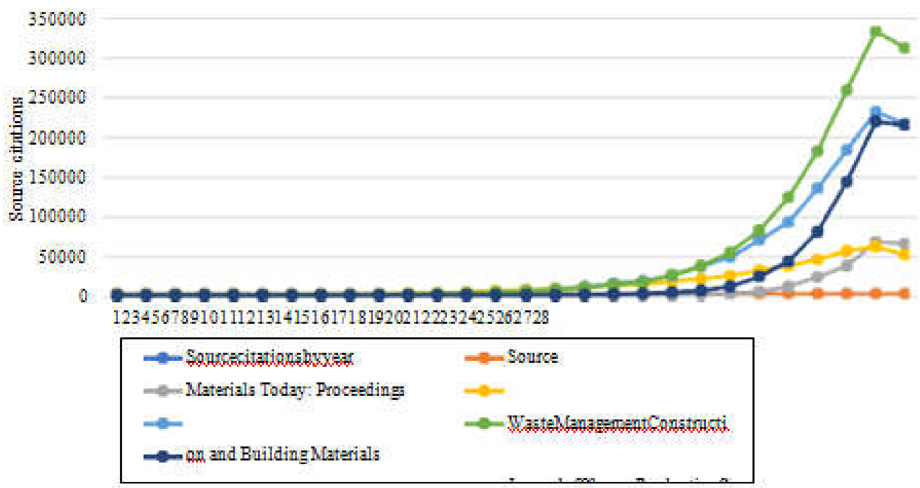
Source:Self-createdbyusingVOS-Viewer

Figure22CiteScorepublicationbyyear



Source: Self-created

Figure23Sourcecitationsbyyear



Source: Self-created

3. CONCLUSION

The study examined the use of LSW in the construction industry through a thorough analysis of bibliometric data and a literature review. The findings indicate a substantial and increasing amount of research on this topic. The global challenge of waste management, especially LSW, is becoming more significant because of the disparities in waste production among different countries. Nevertheless, this challenge also offers a chance for innovation in the construction industry. Existing literature suggests that incorporating LSW into construction materials can be advantageous, asithasthe potential to enhance mechanical properties and contribute to sustainability. The research conducted by different authors shows different results.Some studies indicate that including LSW components in concrete can improve its strength and durability. However, other studies suggest that more research is needed to find the best way to use these materials.

The bibliometric analysis highlights the important role of key researchers and the collaborative aspectof this field.The high number of citations and publications indicates a strong and dynamic research community. The utilization of sophisticated software tools, such as VOS Viewer, has aided in the comprehension of intricate data sets and the visualization of collaborative networks. This has improved our understanding of the dynamics within the field. The analysis of trends in published articles from databases such as Scopus indicates a significant and rapid growth ininterest and research output, particularly in recent.

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