Sustainable Materials Used as Lightweight Aggregate: (An Overview)

Abdulrasool Thamer Abdulrasool¹, *, Safaa S. Mohammed¹, Noor R. Kadhim¹, Wail Asim Mohammad Hussain¹

¹Civil Engineering Department, Faculty of Engineering, University of Warith Al-Anbiyaa, Karbala, Iraq.

*Corresponding Author Email: abdulrasool.tba@uowa.edu.iq

Abstract. Lightweight aggregates (LWA) are building materials with a lower bulk density than standard construction aggregates. In recent years, the contribution of industry to the circular economy has become a serious concern. Among these, the mining sector is confronted with significant problems relating to the management of a huge quantity of generated waste. The major contemporary task is to address a number of interconnected challenges, including waste management and recycling, conservation of scarce natural resources, reduction of energy use, and reduction of greenhouse gas emissions. Natural aggregates are consumed by the construction materials industry in the range of 8 to 12 billion tons per year. According to reports, the construction materials sector consumes the most energy and scarce natural resources (rocks, aggregates, and water) while also emitting greenhouse gases. In general, using waste material as lightweight aggregate decreases the concrete's overall weight. The materials used as lightweight aggregate in concrete are discussed in this study. According to research, utilizing trash as a lightweight aggregate not only improves the characteristics of concrete but also gives a sustainable approach to minimize global waste.

Keywords: Lightweight aggregate, Waste Recycling, Sustainability, Lightweight Concrete.

1. Interdiction

Resources and energy have recently surfaced as two critical problems for the building industry's long-term viability(1)(2). China is one of the largest waste-generating countries, as in 2018, it generated approximately 1.55 billion tons. This statistic was based on the Chinese National Bureau of Statistics(3). There is a significant impact on the environment resulting from industrial solid waste, as the reuse of waste generated as a result of demolition or other waste with a focus on reaching a minimum level of energy is the best way to develop green buildings. Construction material products might be employed on a big scale in the future if a feasible production or reuse system could be developed(4). CO₂ curing for recycled concrete aggregates is an example of a novel approach(5), geopolymers for recovered waste glass(6)(7), treatments for regenerated cellulosic fibers using microwaves and enzymes(8), and palletization for bottom ash incineration(9) in recent years have been characterized. Researchers all around the world are always looking for new and inventive methods to create the next generation of building materials that are both environmentally friendly and long-lasting(4). In today's construction sector, concrete is the most widely utilized building material. Concrete's strong mechanical and physical properties, when correctly planned and produced, are one of its most notable advantages. It is a very cost-effective and easy-to-use substance for the operation; structural concrete components can be molded into a range of shapes and designs; and it
is a very water-resistant substance(10). The widespread use of standard weight aggregates such as granite and gravel in concrete building has drastically reduced natural stone deposits, resulting in irreparable environmental damage(11).

After water, aggregate is the second most consumed raw resource by humans. Its industry is the principal source of raw materials for infrastructure and building construction, as well as industry and environmental protection, and so plays a critical role. Although artificial lightweight aggregates consume less energy than natural lightweight aggregates, their low density, high porosity, inert nature, and reasonable mechanical strength enable them to be used in a wide range of applications, including lightweight concrete, horticulture, geotechnical engineering, masonry, pavements, water treatment and green roofs(12). Although the lightweight aggregate sector has been “stagnant” for several decades, rising environmental concerns and the significant benefits of lightweight aggregate should boost production in the future, as a result, the market for lightweight and thermally insulating concrete is projected to expand(13).

LWAs (lightweight aggregates) are a type of porous low-density aggregate that has been frequently utilized in concrete to minimize building weight. It has increased in recent years, especially in China, Europe and America. Back-weight aggregate has been used as an internal maturation of concrete as a result of its high effectiveness(14). These broad uses eat up a lot of nonrenewable natural resources all around the world. As a result, scholars have taken a keen interest in the use of various aggregates and the concrete that results. Although abuse has resulted in resource shortages in certain nations or areas, LWAs are currently primarily collected from natural sources(15). As a result, using artificial LWAs is an essential approach to address this problem(4).

The microstructure of lightweight aggregate (LWA) influences properties such as density, water absorption, aggregate strength, and their proportional effect on concrete. The microstructure of aggregate is influenced by the raw materials used and the hardening methods used(16).

Sintering and cold bonding are the two most common methods for creating artificial LWAs. Sintering is a method of altering the structure and density of materials without melting them to the point of liquefaction using heat or pressure(17). Fly ash (FA)(18)(19), perlite(20), ceramist(21), and some waste materials(21)(22) in the production of low-density concrete, are often used to sinter LWAs(4).

This study aims to examine the materials that can be used as lightweight coarse aggregate, the majority of which are natural materials that have no use or are waste or materials resulting from waste treatment, and which, if benefited from and used in lightweight concrete on a large scale, could produce positive results in terms of reducing global pollution.

2. Concrete Sustainability

Areas with a lot of urban expansion tend to run out of aggregate sources after a lengthy time of concrete manufacturing. For the purpose of reducing damages to buildings and extending their productive lives, the engineering staff must examine the entire life cycle of the buildings. Even after the work of the buildings, the possibility of recycling the largest part of the demolition waste and recycling should be taken into account so that it can be reused again(23)(24). In accordance with the requirements established by the United Nations Commission on Development and Environment, it is important to be able to fulfill the requirements of today's work without infringing on the right and requirements of future generations to live(25). In recent decades, the increased consumption of natural resources has been the important thing that has helped to increase global warming and increase seawater levels above their previous natural levels, in addition to threatening different types of living and organisms at the risk of mass extinction(26).
Each year, 60 percent of the raw materials extracted are used for construction and infrastructure. The structure accounts for about a quarter of all global extractions(28). The initial period of building construction is the most energy consuming period, as approximately 67 of the total energy of the structure during its total life is consumed during the construction period(29). Furthermore, most structures, with the exception of monuments, must be destroyed at some time. Concrete accounts for more than 75% of all building materials by weight, so it's no wonder that it's the most frequent demolition waste(30). Since one of the most prevalent types of waste is building demolition waste, reducing it and seeking to reuse it is an important matter that leads to enhancing the environment and preserving public health and is a good starting point for following the requirements of sustainable buildings(29). Concrete only developed many solutions that would use recyclable materials in its production. As for building materials, there is a lot of development around the greatest possibility of reducing the energy used during the operating period(31). For the purpose of advancing the reality of sustainable development, it is necessary to move towards renewable resources and to move away from non-renewable resources in order for the shift from generating waste to consuming all kinds of waste through recycling(32).

3. Materials
Riley(33) lightweight aggregate is created when two circumstances occur at the same time, as stated more than sixty years ago:

i) The development of a viscous phase occurs at temperatures around the melting point (but never reaching it, since only some phases become fused).

ii) The release of gas (usually CO₂, CO, H₂O, H₂, O₂, SO₂ or Cl₂) as a result of the breakdown of a variety of organic and mineral substances (such as calcite, dolomite, phyllosilicates, metallic sulfides, chlorides or ferrous minerals, among others).

The gas is imprisoned inside the viscous matrix and pore development is thus stimulated only if these two criteria are satisfied simultaneously. In contrast to the size of the initial pellet, this process is generally followed by a considerable volume increase (bloating or expansion). Natural and manufactured lightweight aggregates are the two forms of lightweight aggregate.
3.1. Natural lightweight aggregate

3.1.1. Pumice

The origin of the word pumice is a Latin word that appears as a result of presence of high-porosity stones. The pumice stone is one of the natural stones produced by the rapid cooling of lava, which has a spongy internal structure with high pores. The small bubbles collected during the lava flow are the main reason for the formation of this spongy structure. The pumice stone has a whitish gray exterior. The external color of the pumice stone is greatly affected by its chemical composition. As a result of this high porosity, pumice acquires unique qualities such as good thermal insulation and acceptable resistance despite its high porosity, which makes it a good material that can be used as a lightweight aggregate(34).

![Figure 2. Natural pumice stone(34).](image)

3.1.2. Attapulgite

Attapulgite clay (also known as attapulgite) is a crystalline hydrated magnesium aluminum silicate with a unique chain structure that gives it unique colloidal and dynamic properties. It is the most common type of fuller's earth, which is a collection of sporting clays(35). In Iraq, research on attapulgite, a native clay mineral, began with the manufacture of mineral admixture from raw materials gathered in the Tar Al-Najaf region. Al-Aride investigated the feasibility of utilizing native clays from the southwest of Iraq as a coarse aggregate in 2014. The study was divided into two parts: part one was for making coarse aggregate (LWA) and determining the appropriate burning temperature, and part two was for generating (LWAC) from the manufactured aggregate. At a treatment burning temperature of 800°C, the bulk density of the Attapulgite lightweight aggregate (ALWA) was 808 km/m3, and the dry specific gravity was (1.45). (1100 C)(35).
3.1.3. Diatomite
Diatoms are one of the most ancient types of algae, as there were about 25,000 different species of them. And after her death and decomposition, she built a thick layer with time. And after being buried and pressed, chalk rocks are generated, which are distinguished by their cellular structure, which is suitable for use as an internal ripening aggregate.

3.1.4. Volcanic slag
Open-pit mining has transformed natural vesicular glassy lava rock into an industrial substance known as volcanic slag. For over three centuries, volcanic slag has been successfully used in over 70 different applications all over the globe. This material's open structure and outstanding drainage characteristics, crushed and screened into necessary sizes, making it a really flexible product for landscaping and under-soil drainage applications. During volcanic eruptions, the lava begins to eject to high distances, as this lava contains many air bubbles, and during its flight, it begins to cool and solidify, resulting in black rocks with high pores. This type of rock provides good properties such as good sound and thermal insulation with a low amount of shrinkage. Volcanic slags are lightweight accumulations of volcanic tailings. Volcanic slag contains many cavities in its structure, which makes it highly porous and light in weight.
3.2. Artificial lightweight aggregate

3.2.1. Oil Palm Shells (OPS)

Malaysia is the main palm oil-producing country, as more than half of the palm oil production in the world comes from Malaysia. However, it is considered a major source of pollution, as 2.6 tons of this solid waste is produced annually, especially as this number is increasing exponentially with the increase in global demand for Palm oils. In 1985, Abdullah of Malaysia was the first to explore the use of OPS as a lightweight aggregate in the production of lightweight concrete. Several studies have shown that it is possible to use the leftover husks from the palm oil industry as a lightweight coarse aggregate. As its cellular structure enables it to be used as a lightweight aggregate.

3.2.2. Ceramic Waste

Garbage and waste generated as a result of the vast increase in the population are one of the challenges facing the world. Many of the items that are discarded are recyclable and should be. There are few attempts to recycle waste and use it in new buildings, and one of these materials is ceramic waste. Recently, there has been a lot of research trying to find acceptable solutions for the use of ceramic as a lightweight aggregate in concrete in order to reduce the increase in waste and reduce its impact on the environment.
Campos and Paulon claim that (48), the use of ceramic as a lightweight aggregate in concrete is of high benefit due to the porosity that the ceramic enjoys, in addition to its good thermal insulation and light weight. Given this background, it is important to investigate the material's potential reuses, one of which is the use of ceramic waste as coarse aggregate in the manufacture of structural concrete. In this scenario, structural elements made with these alternative concrete mixes must fulfill the required design requirements, focusing on building safety in both environmental and fire conditions. Studies have shown that the use of ceramic as a lightweight aggregate sometimes reduces the strength of concrete, but with this reduction, it is acceptable for use (49).

3.2.3. Sewage sludge
The last by-product of the wastewater treatment industry is municipal sewage sludge (SS). With the fast growth of urbanization, the amount of SS produced worldwide is rapidly increasing. Due to the presence of organic and inorganic chemicals, as well as a variety of bacteria in the sludge, landfilling such a huge volume of SS would result in significant land use and pollution concerns (51). Many researches have been done on the recycling of SS in the construction industry. The amount of SS in those above-mentioned construction materials, however, is limited to less than 30% (52). The manufacture of lightweight aggregates is a more appealing alternative method for repurposing SS (LWAs) (53). There has been a lot of research into the manufacturing of LWAs using SS. According to earlier research, the quality of the LWAs created using SS had equivalent characteristics to those made with clay (51).
3.2.4. Waste glass powder
Trash glass (WG) is a type of solid waste, and its repurposing has sparked a lot of interest due to the ever-increasing landfill strain. Previous research has shown that adding glass lowers the sintering temperature, resulting in improved sintering reaction during LWA manufacturing, since glass contains a specific quantity of Na2O, which leads to a lower melting point. Furthermore, at high temperatures, Na2O can lower the viscosity of the liquid phase, which is advantageous in the manufacturing of sintered goods(55).

![Figure 9. Utilized lightweight aggregates (LWA) (waste glass)(55).](image)

3.2.5. Drilling shale cuttings
The treatment of drilling waste is one of the most difficult to perform due to the high cost and the need for high energy, in addition to the lack of the required technologies for this(56). Since this type of waste is one of the most deposited materials during this process, the accreditation began to find appropriate ways to reuse it again(57). In this instance, the cuttings were stabilized and consolidated to create a geotechnical sound filler(58). Studies have shown that it can be used as a lightweight aggregate in concrete mixes.

![Figure 10. Drilling cuttings lightweight aggregate appearance and internal structure(59).](image)
3.2.6. Incineration fly ash and reaction ashes
Large incinerators produce ash deposits in incinerator screens. These ash are usually of three types, the first is light fly ash, the second is heavy ash deposited at the bottom, and the third is a mixture between fly ash and bottom ash(60). Among the incineration waste there are highly toxic substances that exceed the possibility of toxic filtration requirements, such as fly ashes and reaction ashes. Industrial wastes that have been shown to be dangerous must be handled and controlled with great care. Most hazardous chemicals have been demonstrated in the literature to be stabilized by the high temperature solid solution technique, and the resultant consolidation matter may be safely handled or repurposed as building materials(61). Heat treatment, according to Wunsch et al., renders heavy metals in waste inert against leaching(62). According to Sakai and Hiraoka, thermal treatments that are carried out on the incineration waste reduce the effect of harmful substances and make the toxic substances stable to some extent(63). Mangialardi researched the possibility of using this waste as lightweight aggregate in concrete(64). He discovered it can be used as aggregate in concrete as it improves the mechanical properties of concrete(65).

Figure 11. Sintered incineration fly ash and reaction ash aggregate appearance(65).

3.2.7. Incineration of solid waste
The waste hierarchy should be utilized to offer sustainable waste management and resource efficiency solutions in order to transition to a low-carbon economy, due to the rising volume of residual waste. This entails creating long-term solutions for repurposing various types of trash by transforming them into secondary resources. Due to increased demand and limited disposal capacity, municipal solid waste (MSW) incineration in waste-to-energy facilities is predicted to expand across the world(66). Incineration decreases the weight and volume of MSW by around 75% and 90%, respectively, but it still creates substantial volumes of ash, notably incinerator bottom ash (IBA) and air pollution control (APC) fly ash. IBA is the most important MSWI waste, accounting for 85-95 percent of the solid residue left after combustion. It's a non-hazardous waste that may be used as a secondary raw material after being weathered for 2–3 months to immobilize heavy metals(67). Heavy metals that are integrated or incorporated into the neo-formed crystalline or vitreous phases have been demonstrated to be greatly reduced when sintering at high temperatures(68). Despite the fact that the leaching potential reduces as the processing temperature rises, sintering IBA to generate lightweight aggregates (LWA) at temperatures around 1100 °C results in a significant reduction in the leaching potential(69).
3.2.8. Red clays
During open-pit mining, enormous volumes of diverse interlayers made up of limestone, marls, clays, and flintstone are drilled and blasted in order to obtain sedimentary phosphate ores. Because they're generally located in waste rock piles, they're also known as trash mines. The utilization of phosphate mining waste rocks (particularly red clays) to reduce mine footprints and environmental consequences has become a major concern. This is also true of the rising demand for construction materials, which has the unintended consequence of disrupting fragile ecosystems. Many potential environmentally friendly solutions, particularly those linked to phosphate mining, have been created through numerous studies. Their different wastes can be utilized as raw materials in the construction sector to make bricks and membrane filters(70), geopolymers(71), lightweight aggregates(72), road construction(73) and natural stone products(74).

3.2.9. Thermostone
Thermostones are cellular concrete blocks (also known as autoclaved aerated concrete). In multistory structures, these blocks are increasingly being utilized as a brick alternative to decrease overall weight while maintaining thermal comfort. Thermostone is often made from lime, salt, and cement, along with an aluminum powder and water admixture. The key reason for adding aluminum powder is the nutritious bubble structure of the Thermostone. This structural structure is the consequence of the chemical interaction of silica, hydrated lime, and aluminum powder(75). It's also feasible to recycle the trash generated by these concrete blocks to create a lightweight aggregate(76).
Figure 14. Crushing of Thermostone(77).

4. Conclusions
The use of lightweight concrete is of great benefit because it significantly reduces the weight of the structural members. The use of lightweight aggregates resulting from waste reduces global pollution problems and is considered one of the aspects of sustainability. Most of the exposed materials are either waste or unused materials or by-products of accidental industries, so they are widely available in most countries. The use of this technology in Iraq in a large way greatly reduces the problems of pollution, since Iraq relies heavily on natural aggregate quarries in construction.

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