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The Use of Lightweight Aggregate in Concrete: A Review

Saad Muhammad Selman
M.sc student
College of Engineering
University of Baghdad
Baghdad-Iraq
saad.alwan2001m@coeng.uobaghdad.edu.iq

Dr. Zena K. Abbas
Asst. Prof
College of Engineering
University of Baghdad
Baghdad, Iraq
dr.zena.k.abbas@coeng.uobaghdad.edu.iq

ABSTRACT

One of the artificial lightweight aggregates with a wide range of applications is Lightweight Expanded Clay Aggregate. Clay is utilized in the production of light aggregates. Using leftover clay from significant infrastructure development projects to manufacture lightweight aggregates has a favorable environmental impact. This research examines the expanded clay aggregate production process and the impact of processing parameters on its physical and mechanical qualities. It also looks at secondary components that can be used to improve the qualities of concrete with expanded clay aggregates. The effect of the quantity of expanded clay aggregate on the fresh, hardened, and durability qualities of concrete is also studied. Expanded clay aggregates improve workability, fire resistance, sound insulation, and thermal insulation in concrete. Its inclusion, on the other hand, diminishes concrete's density, strength, elastic modulus, and resistance to freeze-thaw action.

Keywords: : Lightweight concrete, LECA, sand lightweight concrete, lightweight aggregate .

استخدام الركام خفيف الوزن في الخرسانة: مراجعة

سعد محمد سلمان
طالب ماجستير
كلية الهندسة-جامعة بغداد

د. زينة خضير عباس
استاذ مساعد
كلية الهندسة-جامعة بغداد

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*Corresponding author

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الخلاصة

احد أنواع الركام الصناعي خفيف الوزن يستخدم مجموعة واسعة من التطبيقات هو حصى الطين المتوسع خفيف الوزن . يستخدم الطين في إنتاج الركام الخفيف .استخدام بقايا الطين من مشاريع تطوير البنية التحتية الرئيسية لتصنيع الركام خفيف الوزن له تأثير بيئي إيجابي .يستعرض هذا البحث عملية الإنتاج الكلي للطين الموسع وتأثير ظروف المعالجة على صفاته الفيزيائية والميكانيكية .كما يبحث في المكونات الثانوية التي يمكن استخدامها لتحسين جودة الخرسانة باستخدام ركام الطين الممتد .تمت دراسة تأثير كمية حصى الطين الموسع على صفات الخرسانة الطرية والمتصلبة .يعمل الركام الطيني المتمدد على تحسين قابلية التشغيل ومقاومة الحريق وعزل الصوت والعزل الحراري في الخرسانة .من ناحية أخرى ، فإن استخدامه يقلل من كثافة الخرسانة وقوتها ومعامل المرونة ومقاومة تأثير التجميد والذوبان.

الكلمات الرئيسية: خرسانة خفيفة الوزن ، LECA، خرسانة خفيفة الوزن بالرمل ، ركام خفيف الوزن.

1. INTRODUCTION

Oldest widely used construction material in the world. The properties of concrete depend mainly upon the properties of ingredients. It has high compressive strength and lesser corrosive and weathering effects. But, its high density increases the structure's weight, affecting construction costs. This drawback of concrete can be reduced by incorporating lightweight aggregates into concrete instead of conventional coarse aggregates. One such lightweight aggregate is Light Expanded Clay Aggregate (LECA), which is made by heating clay in a rotary kiln to 1200°C. LECA is a spherical creature with a continuous network of pores. LECA can be used to make lightweight blocks, concrete, separation panels, thermal insulation tiles, fireproof roof gypsum, and concrete batches. Concrete with a density of less than 1850 kg/m3 and compressive strength of less than 17 MPa is known as lightweight structural concrete. Using LECA in concrete provides many benefits and only a few drawbacks that can be mitigated by utilizing secondary components. The purpose of this study is to review the qualities of LECA, its processing conditions, and its impact on concrete properties. This research also sheds light on secondary components that can be used to improve the concrete qualities of expanded clay particles. Expanded clay aggregates are employed in various sectors because of their technical characteristics and several advantages over other industrial raw materials. Expanded clay aggregates are one of the materials with the highest compressive strength among lightweight aggregates. As a result, it occupies a prominent role in the building sector. In buildings using Light Weight Expanded Clay Aggregate, 20 percent in reinforcing steel can be saved, and up to 50 percent in heating and cooling costs can be saved (LECA) **(Shafigh, Pet., al 2018)**. Expanded clays are clays that, when heated, can expand up to 5–6 times their original volume due to gas release. A hard sintered crust forms on the outside, while inside, light and highly durable aggregate with a porous clinker-like structure may form **(Bernhardt, M. et al., 2014).**

2. REVIEW OF LITERATURE

2.1 Characteristics of Lightweight Aggregates

The characteristics of the clay used to make the lightweight aggregates were examined. For usage in concrete, an ideal clay lightweight aggregate should be generally spherical, 4–14 mm in diameter, robust, and porous. Clay's porous nature is a fundamental determinant of concrete density, water absorption, and strength. The high temperature used to make light expanded clay aggregate resulted in continuous pores, which increased the aggregate's porosity. Pore size and porosity decreased as the temperature was elevated above the pyroplasticity range. The gradual cooling of LECA during manufacture improved aggregate crushing strength. **(Bamdad Ayati et al., 2018)**.

The properties of light expanded clay aggregates, which are employed as fine and coarse aggregates in concrete, were examined. The workability of the concrete was found to improve as the amount of pre-wetted LECA used as coarse or fine aggregate was increased. LECA's increased water absorption has a detrimental impact on concrete workability. On the other hand, the round nature of LECA has a favorable effect on concrete workability. Additionally, the implementation of LECA reduced segregation. LECA was used as coarse and/or fine aggregates in concrete, resulting in a lower density. The reduced specific gravity of LECA in comparison to the regular weight aggregate was the reason for this. In addition, as compressive strength increased, the density of LECA-containing concrete increased.

Creep and shrinkage were minimized when rewetted LECA was added to concrete. The mechanical strength of concrete decreased as the quantity of expanded clay aggregates increased. Adding coarse and fine LECA to concrete lowered its strength even more. LECA is porous and has lower crushing strength. Compared with traditional coarse aggregate, the round shape of LECA resulted in lower bonding strength with the surrounding concrete. The use of expanded clay particles in concrete boosted water absorption while decreasing chloride penetration. The inclusion of LECA improved the fire resistance of concrete. This could be attributed to LECA's limited thermal expansion as well as its exposure to high temperatures during manufacture. The reduced resistance to freezing and thawing was noted, which could be attributed to expanded clay particles' increased water absorption. LECA's porous structure, low density, and low thermal conductivity improved the concrete's sound absorption and thermal insulation qualities. Using LECA instead of silica fume improved the concrete's mechanical strength and chloride penetration resistance. However, there was a decrease in the slump **(Alaa M. Rashad, 2018)**.

2.2 Study of the properties of fresh and hardened concrete.

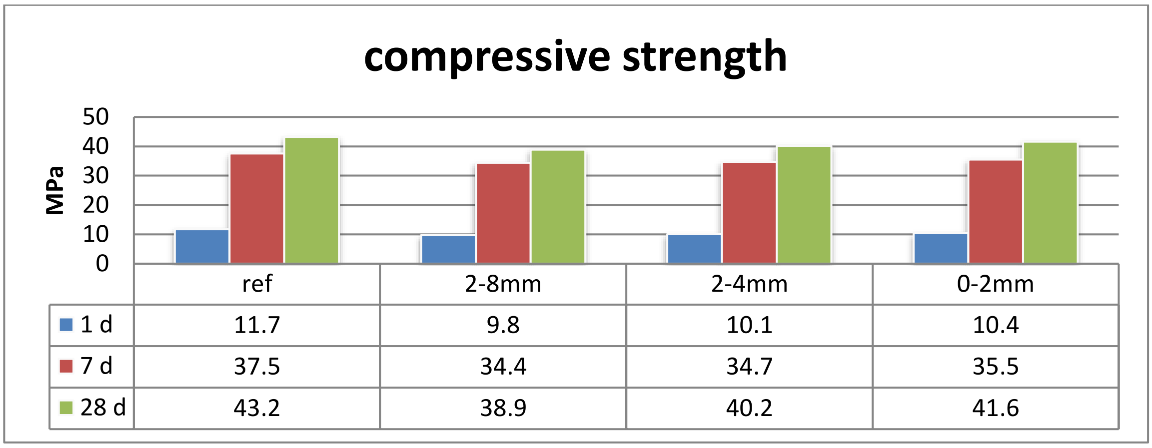
Experimented with light expanded clay aggregates as a partial replacement for coarse aggregates. Replacement percentages of 50 percent, 60 percent, 70 percent, 80 percent, and 90 percent were used to create five mixtures. The qualities of fresh and hardened concrete were investigated. The density of concrete fell as the proportion of replacement increased, but the workability of concrete increased. With increasing proportions of light expanded clay aggregates, compressive strength, flexural strength, and split tensile strength all decreased. It was determined that replacing conventional aggregates with expanded clay aggregates 70 percent of the time offered the best outcomes **(Ming Kun Yew et al., 2020)**.

The strength of the aggregate does not just determine the compressive strength of the generated concrete; the Interfacial Transition Zone (ITZ) also plays a vital role in influencing the strength of the LWAC **(Shafigh P. et al., 2014).**

Additional internal curing water is added to the concrete mixture by replacing a portion of the usual weight aggregates with pre-wetted lightweight aggregates (LWA). Internal curing water will be drawn from the LWA into the hydrating paste during the hydration of the cement paste within the concrete mixture, maintaining a high degree of saturation (water-filled pores) in the cement paste and avoiding or at least reducing shrinkage stresses and their associated autogenous deformations **(Fawzi and AL-Awadi, 2017).**

There is a tremendous need to use alternative materials for sustainable development as demand for construction materials rises. The main objective of this research is to look at the characteristics of lightweight concrete, including expanded polystyrene (EPS) beads, such as compressive and tensile strength. Its qualities are compared to ordinary concrete, which does not contain EPS beads. EPS beads partially replace fine particles. The findings revealed that the number of polystyrene beads in concrete impacted the qualities of hardened concrete. Because the compressive strength varies depending on the amount of replacement, it is less than a specific percentage. The compressive strength of EPS-based concretes was found to be 5 percent, 15 percent, and 20 percent higher at 28 days than control concrete **(Aljalawi, N. M. F. 2019).**

A study of the use of lightweight LECA total weight of different sizes was done**.** The water absorption of LWA is 13.5%. There are five mixtures; first is reference mix (without LWA), second, replacement fine, normal aggregate with fine LWA (11.5%) with (0-2mm) size. Third, replacement fine, normal aggregate with fine LWA (11.5%) with (2-4mm) size. Fourth, replacement coarse normal aggregate with fine LWA (11.5%) with (2-8mm) size. Fifth, replacement both fine and coarse normal aggregate by (11.5% LWA) from total aggregate with (0-8mm) size. The compressive strength result shows the internal curing mixture having slightly lower compressive strength than the reference mix. Also noted is the compressive strength effect by the size of aggregate, and a mix with (0-2mm) has maximum compressive strength, but a mix with (0-8mm) has lower compressive strength. **Fig. (1)** shows the compressive strength with different gradations **(Kyllastinen et al., 2015)**.



	ref	2-8mm	2-4mm	0-2mm
🟦 1 d	11.7	9.8	10.1	10.4
🟥 7 d	37.5	34.4	34.7	35.5
🟩 28 d	43.2	38.9	40.2	41.6

Figure (1) The Compressive Strength for Different Gradation of LWA (Kyllastinen, 2015)

Experimentation on M40 grade concrete varied with percentages of expanded clay particles replacing traditional coarse aggregates. 0 percent, 20 percent, 40 percent, 60 percent, and 80 percent replacement of coarse aggregates were used in five different mix proportions. Adding LECA to concrete lowered its density while improving its workability. After the third and seventh days of curing, the compressive strength of each mix was determined. A decrease in compressive strength was seen as the fraction of LECA replacement increased. The workability of lightweight concrete was observed to diminish as expanded clay aggregate was added, which contradicts earlier research. Increased expanded clay aggregate content reduced the density of concrete **(Ayswarya R. et al., 2018)**.

This study looked at how to reduce the weight of concrete while maintaining compressive strength of 29.85 N/mm² when 20 percent LECA was replaced by natural coarse aggregate and 25.40 N/mm² when 40 % LECA was replaced by natural coarse aggregate when treated at 28 days, and we could also see just an improvement in compressive resistance if it was cured for 60 days and more. By lowering the concrete's weight reducing the cost of spending on the foundation allows us to minimize the static weight of concrete and hence the cost of building. When compared to normal concrete, concrete, lightweight expanded clay aggregate (LECA) has a lower density of lightweight aggregate **(Rajprakash and Krishnamoorthi, 201**7)

The production of new cement-based materials with high strength, low density, and strong thermal qualities for energy-efficient structures was investigated. Pumice, expanded clay, perlite, and rubber aggregates were used in varying volume fractions of 10 %, 20 %, 30 %, 40 %, and 50 % of concretes having normal aggregates replaced by lightweight aggregates. Adding pumice, expanded clay, and rubber aggregate to composite concretes lowered the material's bulk density and compressive strength while improving the insulating properties. **(Oktay and Yumrutas, 2015).**

The effects of coarse lightweight local attapulgite aggregate (LWAA) on several concrete mechanical properties were investigated. The experimental test results for compressive strength were 27.7 MPa and oven dry density 1824 kg/m³ at curing ages 7, 28, and 56 days. The results showed that using LWAA as a coarse aggregate with a cement and natural sand concentration of 540 kg/m³ increased compressive strength, flexural strength, splitting tensile strength, and static modulus of elasticity significantly **(Al-Aridhee, M. J. H. 2014).**

The relationship between density and elastic modulus of light expanded clay aggregates was investigated. Because of the low density of LECA, the modulus of elasticity of concrete decreased exponentially as the volume fraction of LECA increased. The relationship between LECA density and modulus of elasticity was discovered to be linear. When LECA was added to concrete, the Poisson ratio of the concrete increased in **Fig. 2 (Ardakani A. and Yazdani M., 2014)**.

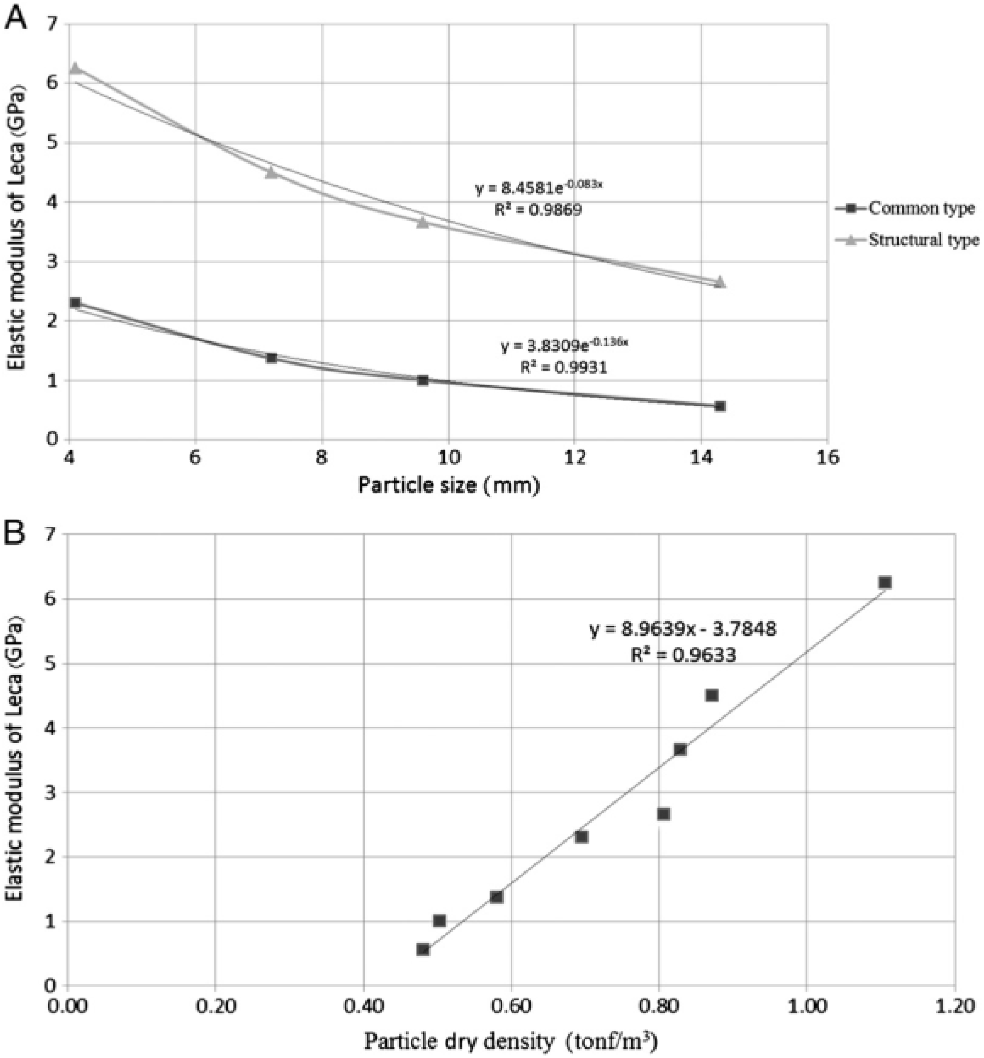


Figure 2. Elastic moduli of aggregates versus particle size and particle dry density **(Ardakani and Yazdani, 2014)**.

The partial replacement of M25 grade concrete, whose mix design was determined using IS 10262:1982, was tested. Twenty percent, forty percent, sixty percent, eighty percent, and one hundred percent replacement percentages of coarse aggregate with LECA were used to create five distinct mixtures. The density and strength of concrete dropped linearly as the replacement percentage rose. After 60 percent coarse aggregate replacement, the compressive strength of concrete was less than 25 N/mm². However, the strength of 100% LECA concrete was better than 17 N/mm², allowing it to be employed as lightweight structural concrete. **(Sonia, T. et al.,2016)**.

2.3 Comparison between normal concrete and concrete containing lightweight aggregate

(Aljubori et al., 2019) studied the feasibility of using waste plastic as one of the components of lead-acid batteries to substitute fine aggregate in concrete masonry units by 50 to 70% by volume. Results showed a reduction in density of roughly 32.5 percent to 39.6 percent for replacement of 50 percent to 70 percent, respectively, compared to the reference concrete mix. The compressive strength was reduced after 28 days of curing, but water absorption was raised by increasing the waste plastic percentage. The amount of lead ion recovered from the waste lead acid battery plastic (WLABP) modified concrete was within permissible limits, according to the leaching test. The outcomes of this study pointed to a long-term alternative approach for lowering the environmental impact of waste plastic from lead-acid batteries**.**

A comparison of traditional concrete's strength and elastic characteristics with lightweight concrete with expanded clay aggregates was presented. Three concrete mixtures were created with typical coarse aggregate and two types of expanded clay aggregates. After 28 and 120 days of curing, the dry unit weight and compressive strength of concrete were determined. Concrete's density grew in general as its compressive strength increased. Even for concrete with a low watercement ratio, expanded clay particles with high water absorption produced superior internal curing. The modulus of elasticity of concrete increased in lockstep with its strength **(Murat Emre Dilli et al., 2015)**.

Another study used LECA to examine the elastic characteristics of traditional concrete with lightweight structural concrete systems. To evaluate a considerable shift in elastic characteristics with noticeable differences in density, the study kept both the amount of total aggregate and the water-cement ratio constant **(Bogas et al., 2012).**

4. Recycling of building waste

The effect of using recycled aggregates as the concrete aggregate and the effect of using recycled aggregates on the characteristics of concrete masonry units were investigated. Crushed, sorted, and classed brick waste into coarse and fine aggregates and clay brick powder (CBP). The test results revealed that when the cement paste is changed with 25% CBP, it has a smaller pore size and less weight loss when exposed to higher temperatures than the reference paste. Using recycled aggregates also reduces the overall unit weight of concrete masonry units. Crushed clay brick, besides being used as an alternative aggregate, has somewhat unfavorable impacts on concrete porosity and mechanical qualities, which limits its use in many structural applications; nonetheless, it has other benefits. It lowers concrete density, resulting in cheaper transportation costs and dead load, and it has the potential to be used as fire-resistant concrete (**Alioddo and Abd- Elmory, 2014**).

The idea of employing waste plastic as one of the components of expired lead-acid batteries to make lightweight concrete is investigated in this study. Different amounts of lead-acid battery plastic were used to manufacture lightweight concrete. The fine and coarse aggregate replacements were (70, 80, and 100 percent) by volume. When 70% to 100% of the natural aggregate was replaced with lead-acid battery plastic, the wet density was reduced by roughly 23.6 percent to 35 percent. Also, at varied curing ages of 7, 28, 60, 90, and 120 days, the compressive strength declined marginally as the plastic content increased. At (120) days of test age, the lowest result of compressive strength was (20.7 MPa) for (waste plastic =100%. The addition of waste plastic decreased the heat conductivity of the concrete as compared to plain concrete, and this attribute is decreased due to an increase in the proportion of waste **(Aljubori et al., 2018).**

With increased plastic substitution, the compressive strength of concrete containing plastic diminishes (20 percent decreases with 1 percent of the addition of plastic bag pieces). Adding up to 0.8 percent of plastic bag fragments to the concrete mix, on the other hand, increased the tensile strength of the concrete **(Qasim et al., 2021)**.

This research studied the use of crushed concrete debris as a filler for hollow concrete masonry units. The major goal was to raise the value of concrete waste to create a sustainable and profitable disposal option. To manufacture hollow concrete blocks, attempts were made to use the concrete waste as crushed stones in the concrete mix. The amount of crusted stones has been tried at various percentages (i.e., 0 percent, 10 percent, 20 percent, 50 percent, and 100 percent). Based on the findings, they discovered that concrete debris can be used to make hollow concrete block masonry units **(Thaniya, 2010)**.

The effect of coarse aggregate on total aggregate ratio and maximum size of coarse lightweight aggregate, as well as the possibility of using crushed thermostone aggregate as a partial and complete replacement for conventional coarse aggregate in the production of lightweight concrete, were investigated. The testing findings showed that lightweight concrete with coarse LWA (coarse lightweight aggregate to coarse lightweight aggregate ratio is 100 percent by volume) is compressive strength of up to 11.44 MPa after 28 days and an air dry density of 1520 kg/m³.

5. Merging a secondary material on a lightweight aggregate

Experiments were conducted on conventional concrete in which the coarse aggregate was substituted with expanded clay aggregate in 0%, 25%, 50%, 75%, and 100%. There was also 10% silica fume and 1.6 percent polyvinyl alcohol fibers in the concrete. After 7 and 28 days of cure, concrete specimens were tested for compressive and flexural strength. Concrete's compressive and split tensile strength decreased as expanded clay particles aggregate **(Divya et al., 2017)**.

The ability to use recycled brick aggregate in concrete is determined mainly by its quality and properties. The main drawbacks of recycled brick aggregate (RBA) are its high water absorption, which reduces the workability of fresh concrete, and excessive contaminants, which might degrade the mechanical qualities of concrete (**Abbas and Abd, 2021**)

(Sureshchandra et al., 2014) determined the compressive strength of hollow blocks with quarry dust as a partial or complete replacement for sand. He discovered that 50 percent sand replacement resulted in strong strength, and 100 percent sand replacement resulted in low strength after replacement.

The durability of lightweight concrete comprised of expanded clay aggregates was tested. With variations in the admixture employed, five mix patterns were created with a consistent proportion of lightweight expanded clay aggregate and natural dense stone. Black coal fly ash was used to replace 40% of the cement in Mix I-A. Mix I-B and Mix IC were created by replacing 5% of the cement in Mix I-A with metakaolin and micro silica, respectively. Micronized limestone was used to replace 40% of the cement in the mix, resulting in Mix ID. After 180 days, the specimens were put through a compressive strength test. Carbon dioxide, sulphates, chloride ions, and diesel oil were also investigated. The mix I-A was found to have a high resistance to carbon dioxide and sulphates in the testing. The corrosion resistance of Mix I-B was higher than that of the other concrete mixes. Thus, it was discovered that replacing cement with black coal fly ash and metakaolin increased the durability of concrete using porous expanded clay aggregates **(Michala and Rudolf, 2013)**.

Crushed old oil palm shell (OPS) was employed as coarse material in this investigation. The splitting tensile and flexural strengths and compressive strength under various curing circumstances were compared to those of normal weight granite concrete. According to the test results, OPS concrete with a compressive strength of 34–53 MPa has a splitting tensile strength of 2.8–3.5 MPa and flexural strength of 4.4–7.0 MPa. In this investigation, the sensitivity of OPS concrete compressive strength is much lower than that of uncrushed OPS concrete described in the literature. The sensitivity of OPS concrete under poor curing conditions can be minimized by lowering the water/cement ratio, increasing the OPS content, or lowering the cement content. The 28-day compressive strength of OPS concretes cured for 3, 5, and 7 days revealed no significant differences. OPS concrete's 28-day compressive, splitting tensile, and flexural strengths were found to be 38%, 28%, and 17%, respectively, lower than granite concrete. **Fig. 3** depicts the flexural-compressive strength relationship in concrete, with a ratio of 11.6–13.5 percent. (**Shafigh et al., 2012)**.

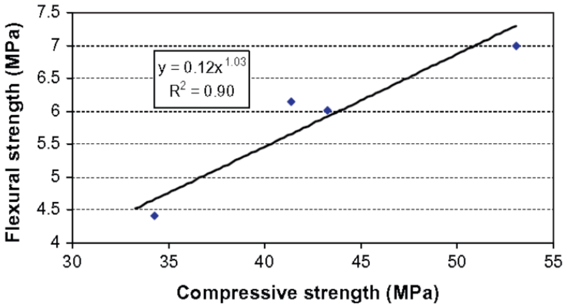


Figure 3. Compressive and flexural strength of OPS concrete after 28 days (**Shafigh et al., 2012**)

The expanded glass was used in a study on the qualities of lightweight concrete, which examined the concrete's mechanical and flexural strengths. The addition of expanded glass granules increased both compressive and flexural strengths, according to the results. Compressive strength increased from 4.0 to 5.8 MPa, and flexural strength increased from 1.5 to 1.7 MPa. In earlier investigations, flexural strength was previously measured to be between 2.13 to 4.93 MPa. The average flexural strength of the 28-day was 13.7 percent. At the same time, 28-day compressive strength ranged from 12.9 percent to 14.8 percent. Flexural strength of high and medium strength lightweight aggregate concrete is generally between 9 and 11 percent, according to the manufacturer **(Bogas et al., 2014).**

3. CONCLUSIONS

The following conclusions were drawn from the literature review:

- The heating and cooling process during the manufacturing of expanded clay aggregates affects the porosity and strength of the aggregates.
- The use of expanded clay aggregate in concrete resulted in increased workability due to the spherical nature of the aggregates.
- Expanded clay aggregates' increased water absorption has a detrimental impact on concrete workability. Segregation resistance has also improved.

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- The use of LECA reduced concrete creep and shrinkage, but the use of light expanded clay aggregates in place of traditional coarse aggregates lowered concrete density, strength, and modulus of elasticity.
- When the density of concrete increased, the compressive strength of the concrete increased as well.
- Due to its low thermal expansion and exposure to high temperatures during manufacture, LECA improved the fire resistance of concrete.

- When LECA was mixed into concrete, the resistance to freezing and thawing was reduced, and the sound and thermal insulation properties of the concrete were improved.

- The use of mineral admixtures such as black coal fly ash and metakaolin can improve the durability of lightweight concrete containing expanded clay aggregates, and the replacement of cement with silica fume in concrete containing LECA improved the compressive strength and chloride penetration resistance.

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