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Review Article

Properties of lightweight concrete utilizing waste materials and artificial aggregates: A review

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ABSTRACT

Lightweight concretes (LCs) have been developed over the past 30 years with the goals of minimizing the volume of components that bear weight, using less raw material and enhancing mechanical qualities. Lightweight aggregates can be used in a variety of production procedures to create these concretes. A number of factors, like the method of manufacturing, the binder used, the mass ratio of cement to water, the porous structure, and the amount of admixture or surfactant, affect the compressive strength of LCs. An essential goal of the building materials and construction industry is environmental protection through waste minimization and sensible use of raw natural resources. Many kinds of wastes have been used as components to create new materials including eco-concrete, geo-polymer concrete, and eco-composites. In unconventional concretes, materials such as fly ash, ground-granulated blast furnace slag, silica fume, tire trash, plastics, glass, and agricultural wastes were substituted for cement or aggregates. Several studies by writers who produced LCs by utilizing various waste kinds and artificial aggregates are included in the article.

Keywords: Compressive strength, eco-concrete, lightweight aggregate, lightweight concrete, wastes materials

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INTRODUCTION

In Europe, the building industry is responsible for about 40% of the total energy demand. The amount of energy used in buildings for space heating and cooling is approximately 60%.[1,2] Present-day filling materials, such as hollow bricks and lightweight concrete (LC), provide a good balance between mechanical and physical characteristics. Nevertheless, these building methods rely on high-energy procedures and noble raw materials. In the framework of sustainable development and energy conservation, lightweight and cost-effective building materials that can be used for both new construction and rehabilitation are essential.

Nowadays, there is no doubt about the connection between energy use and environmental effects. The construction industry is the second largest source of carbon dioxide pollution in Europe, producing 120 Mt of CO_2 annually, or 32% of all CO_2 gas emissions. By 2020, greenhouse gas emissions from 1990 levels are to be reduced by 20%, according to European standards. In the same timeframe, renewable energy should constitute 20% of final energy consumption.

The issue of natural resources gradually running out and become harder to access is another big challenge that the building industry must deal with. Although there is still a lot of limestone available, which is the primary ingredient in clinker, the demand for cement is always rising. While things have stabilized in industrialized nations, demand is skyrocketing in developing nations such as China, India, the Middle East, and South America.[3,4] Because of its inexpensive price when all sectors are taken into account, ordinary Portland cement (OPC) concrete is the manufactured product that is consumed worldwide the most. Clinker calcination at 1400°C is the basis for OPC manufacturing, and it requires a lot of energy (2900–3300 kJ/t).[5,6] For every ton of cement, the proportional carbon dioxide production is 0·9 t. Eight percent of global carbon dioxide emissions are attributable to the production of OPCs.[3]

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Reducing the amount of cement used to produce concrete and giving emphasis to eco-friendly materials in the new framework of sustainable ecological development is an important consideration. Concrete should be as environmentally friendly as possible and maintain the lowest possible pollution levels in accordance with current standards for environmental preservation. Replacing some or all of the cement needed to make concrete with other materials that have pozzolanic properties is one way to accomplish this goal. A wide range of waste products, including industrial and vegetal sub-products can be added as aggregates in the composition of concrete. Depending on the type of uncommon material used to make concrete, various forms with distinctive qualities can be obtained.

The objective of this article is to provide references for the many LC kinds by classifying them based on their manufacturing processes and related mechanical properties. Producing LCs with strong mechanical performance would therefore be quite interesting, especially considering the status of the economy and environment at the moment. OPC is used to make the great majority of LCs, while alternative binders may be taken into consideration. In this case, extra consideration is given to LCs made with lightweight aggregates (LAs) and wastes instead of conventional natural aggregates.

LCs

According to BS EN 206-1, LC is created by substituting either all or some of the dense natural particles with LAs, resulting in an oven-dry density of at least 800 kg/m^3 and no more than 2000 kg/m^3. While not covered by this Standard, this range of densities can be reached if the concrete is constructed using the densest natural aggregates possible while including extra air, as in the case of foamed, no-fines, or aerated concrete.

Any aggregate with a dry loose bulk density of <1200 kg/m^3 or a particle density of <2.0 mg/m^3 is considered lightweight according to BS EN 13055. These characteristics are mostly caused by surface vesicles and encapsulated holes in the particle structure. Appropriate aggregates for structural concrete should have minimal water absorption and a low cement paste concentration.[7] These LAs can be used to produce LC.

LC with Waste Materials

In their work, Ali *et al*., looked at a number of properties of LC made of burnt waste oil ash, polyethylene waste, and volcanic slag.[8] Another study examined LCs with 15%, 30%, and 45% doses of reactive particles, including blast furnace slag, ultra-smooth silica, and polystyrene granules.[9] The characteristics of LC with polystyrene aggregate and additional heat plant ash were examined by the authors Herki *et al*.[10] Experimental results on the mechanical and acoustic properties of concretes with metallic fibers and LA are reported in the work of Mastali *et al*.[11] The process of alkaline activation of slag yields LAs, which are then added to concrete at varying concentrations.

The LC that was evaluated in the study by Chung *et al*. is composed of sand, heat plant ash, expanded clay, and limestone powder.[12] The influence of these ingredients on the characteristics of LC was examined.[12] Shafigh *et al*. also employed limestone powder in their work, which produced LC by substituting 50% and 70% of the cement with fly ash and LAs used in the concrete were manufactured from palm tree bark.[13]

In another research, polyethylene therephthalate (PET) chips were substituted instead of sand in the mix of LCs at percentages of 5%, 10%, and 15%.[14] Rahmani *et al*. also substituted 25%, 50%, and 75% of the smooth aggregate in the concrete composition with some recycled PET trash.[14]

In their study Záleská *et al*., examined the characteristics of several LC compositions that included plastic wastes such as broken polypropylene, re-granulated polypropylene, and fiberglass polypropylene with dimensions <8 mm.[15] Alqahtani *et al*. Used recycled plastic in the composition of LCs products.[16]

Tang and Brouwers investigated the endurance characteristics of a number of self-compacting compositions including artificial LAs made from heated plant ash in their study.[17]

Physical Properties

Allahverdi *et al*., presented the investigation of LCs using reactive powders and polystyrene granules.[9] The authors were able to generate LC with densities ranging from 1257 kg/m^3 to 1840 kg/m^3. The authors came to the conclusion that densities decrease as replacement percentage increase.[9]

Using expanded LAs, various additions, including limestone powder, expanded clay (Liapor), fly ash, and two types of sand (smooth and regular), Chung *et al*. were able to produce LC with a density of <1000 kg/m^3.[12]

Záleská *et al*., found that, for all types of polypropylene aggregates, there was an almost linear decline in bulk density dependent on the amount of plastic waste contained, whereas the matrix density could be decreased by adding polypropylene waste to the concrete.[15]

According to research by Rahmani *et al*., increasing the PET dosage to 15% will result in a 3.1% density drop at a water-cement concentration of 42% and a 3.3% density drop at a 54% water–cement content.[14]

Mechanical Properties

Table 1 represents previous works containing mechanical properties of concrete utilizing waste materials.

LC WITH LAs

The simplest method for creating LC is to add LAs (density, ρ < 1200 kg/m^3) to a fresh mineral suspension to replace some of the OPC concrete's constituent parts. LA concrete (LAC) is the name given to the final materials. From 1350 to 1850 kg/m^3, a large density range is found for LC. In general, local production of LAs is contingent on resource availability. The majority of LAs come from industrial byproducts. The most often utilized are fly ash and blast-furnace slag. These LAs often result in good mechanical performance of the LAC and have the shape of spherical pellets.[22] Metal industry waste

Table 1: Review of LC utilizing waste materials

Reference	Waste utilization	Findings
[18]	Volcanic slag, expanded clay, polystyrene granules	The results for elasticity and compressive strength were<0.6 MPa and<5 MPa, respectively. When the lightweight concrete with expanded clay was compared to the examined concrete, same mechanical characteristics were found.
[9]	Blast furnace slag, ultra-smooth silica and polystyrene granules	The compressive strength values ranged from 20.8 MPa to 85.6 MPa.
[11]	Polyvinyl alcohol fibers, polypropylene and basalt	The concrete's mechanical properties were enhanced by the fiber addition. Compared to other fibers like polypropylene and basalt, the polyvinyl alcohol fibers had the biggest effect, most likely as a result of their effective bonding with the matrix.
[12]	Limestone powder, expanded clay, heat plant ash and sand	For every concrete specimen, a compressive strength greater than 18 MPa was attained.
[15]	Crumbled polypropylene, re-granulated polypropylene and fiber glass polypropylene	The bending characteristic, modulus of elasticity, and compressive strength had all gradually declined as the dosage of plastic particles increased. The re-granulated polypropylene produced the finest outcomes.
[17]	Heat plant ash	The bending and compressive strength of concrete were influenced by the quantity of artificial aggregates used in the material. The resistance of the concrete showed a positive linear connection with the resistance against breaking tiny lightweight particles when 30% of the 0–4 mm type was replaced. However, this relationship was not evident for replacement percentages higher than 60%. When lightweight particles were used in the concrete, the compressive strength of the mixture was directly linked to the gross density of the new concrete.
[19]	Pumice, volcanic tuff and diatomite	The concrete's tensile and compressive strengths increased significantly as its age increased from 3 to 90 days, with a water-to-cement ratio ranging from 0.48 to 0.36. Tensile strength and compressive strength, which ranged from 5 to 61 MPa, were found to have a sufficient linear relationship with the gross density in the fresh state.
[20]	Pumice, metallic fibers and polypropylene fibers	The study found that natural pumice stone could be employed as the principal aggregate in order to produce structural lightweight concrete with a density of 1740–1880 kg/m^3 and a compressive strength of 19–30 MPa. When the dose of polypropylene fibers in hardened concrete was<0.2% of its volume, it had no discernible impact on the material's mechanical characteristics. Although they had a much lower effect on compressive strength (up to 50%), steel fibers continuously enhanced flexural strength (up to 200%).
[21]	Metallic fibers	After 28 days, tests were conducted on all the self-compacting concrete mixes to determine their compressive strength and Young's modulus. The compressive strength results ranged from 30 to 35 MPa. Metallic threads had been added to the concrete mix to increase its flexibility.
[8]	Volcanic slag, polyethylene waste and ash resulted from burning wasted oil	Research was conducted on concretes where the primary aggregate is substituted with polyethylene. The experimental concrete samples exhibited compression resistances ranging from 17 to 27 MPa.

LC: Lightweight concretes

Table 2: Review of LC utilizing artificial lightweight aggregates

Reference	Composition	OPC content: kg/m³	w/c (or w/b) ratio	Paste density: kg/m³	Apparent density: kg/m³	Compressive strength: MPa	Compressive strength test, dimensions (in mm) and age
[29]	Various	Various	-	-	300–1850	0·3–70	Cubic, 28 d
[30]	OPC, LA	200–500	-	Spreading	1970–2040	-	-
[26]	OPC, S, LA	-	w/c=0·35	-	-	18·9–59·1	Cubic+Cylindrical, 28 d
[27]	OPC, LA	280–536	0·42<w/c<0·80	Spreading	1775–2355	38–57	Cubic, 28 d
[28]	OPC, LA, S, SP	300–594	0·3<w/c<0·55	Spreading	1494–2358	28·1–81·6	Cubic, 28 d
[31]	OPC, S, SF, LA, SP	414–826	0·29<w/b<0·46	1605–2156	1453–2107	24·91–85·93	Cylindrical, 28 d
[25]	OPC, FA, LA	338–420	0·54<w/c<0·56	Spreading	1617–1851	29·19–38·58	Cubic, 28 d
[32]	OPC, LA, S, SP	295–317	w/c=0·55	696–2015	392–1992	0·1–28·8	Cubic, 28 d
[33]	FA, oil palm shell, SP	0	-	-	1291–1791	8·3–30·1	Cubic, 28 d
[34]	OPC, LA, S	430–490	w/c=0·45	Spreading	1831–2515	24–40	Cubic, 28 d

Here, OPC: Ordinary portland cement; LA: Lightweight aggregate, FA: Fly Ash, SF: Silica fume, S: Sand, SP: Superplasticizer, w/c: Water to cement ratio, w/b: Water to binder ratio

includes expanded blast-furnace slag. It is made by adding water, which vaporizes when it comes into touch with the blast-furnace slag at high temperatures. This process produces porosity. Fly ash LA is produced using a similar procedure. By applying this LA, LAC is produced that has a compressive strength of 4–25 MPa and a density of 1000–1800 kg/m³. Lightness and mechanical qualities are two criteria used to assess the quality of LA, although they are not the only ones. The fluidity of fresh paste can be significantly influenced by the form of the LA. Erdogan stated that spherical LA is advised since it preserves adequate paste fluidity.[23] Because a highly porous LA may absorb a lot of water, it may be harmful to binder hydration, making permeability another essential attribute. LAs with impermeable shells are favored, according to Nguyen *et al*.[24]

Mechanical Properties

Improved mechanical performance can be attained with a higher OPC concentration in a LAC, regardless of the LA used. Because LAs are typically more brittle than the cementitious matrix, fractures happen in them more frequently.[25] The mechanical properties of LAC are significantly influenced by the size distribution of the LAs. Large LAs are typically more brittle than small ones. LAC performance is directly impacted by the mechanical performance of the LAs. Cui *et al*., state that when the LA volume rises, compressive strength and Young's modulus drop regardless of the LA employed.[26] Superior crush resistance and/or high-density LAs result in improved LAC mechanical characteristics. Haque *et al*., investigated the effects of curing on two OPC LACs and showed that a water immersion cure at 23°C had a beneficial impact.[27] To make these two LACs, fly ash-based LAs with varying compressive strengths were employed. Following 7 days of curing, the results became stable, indicating that a lengthier curing period was not required. The compressive strength values ranged from 45 to 65 MPa, while the densities varied from 1755 to 2355 kg/m³.[27] Bogas and Gomes investigated the impact of LA type using three distinct expanded clay LAs.[28] Furthermore, the mass ratio of water to cement (w/c) was investigated. As it also depended on LA characteristics, the authors noted that the relationship between LAC density and the LA volume used was not unique.[28] Moreover, in contrast to Neville and Uysal *et al*., cement content and sand/cement ratio had no effect on compressive strength for a single w/c ratio.[29,30] Ke validated these findings by demonstrating that if the LA density exceeded 1500 kg/m³, there was no apparent improvement in the compressive strength of OPC concrete (around 40 MPa).[31] It was the mortar that fractured, not the LA. It was discovered that, regardless of the LA used, increasing the matrix quality improved the LAC's Young's modulus. Table 2 represents previous works containing mechanical properties of concrete utilizing artificial aggregates.

CONCLUSION

Construction materials that can be used as partial load-bearing materials are being developed in response to the current economic and environmental conditions. This review suggests that LCs made from wastes or LA are being developed and researched by the scientific community. Several factors, including the presence or absence of LA, the kind and composition of the binder, the production technique, the water-to-binder ratio, etc., vary among the many referred works. Compressive strengths are more widely distributed at the same apparent density. Significant differences can be seen in certain LCs made with the same binder. The choice of binder alone cannot account for these scattered results. These notable differences may be explained by the impact of the porous structure. To demonstrate that these materials are appropriate for partial load-bearing applications, more research on LC durability is necessary.

REFERENCES

1. Özel M. Thermal performance and optimum insulation thickness of building walls with different structure materials. Appl Therm Eng 2011;31:3854-63.
2. Zheng G, Jing Y, Huang H, Gao Y. Application of improved grey relational projection method to evaluate sustainable building envelope performance. Appl Energy 2010;87:710-20.
3. Trends in Global CO_2 Emissions: 2013 Report. PBL Netherlands Environmental Assessment Agency. Available from: https://www.pbl.nl/en/publications/trends-in-global-co2-emissions-2013-report [Last accessed on 2013 Oct 31].
4. Zhang Z, Provis JL, Reid A, Wang H. Geopolymer foam concrete: An emerging material for sustainable construction. Constr Build Mater 2014;56:113-27.
5. Damtoft JS, Lukasik, J, Herfort, D, Sorrentino, D, Gartner EM. Sustainable development and climate change initiatives. Cem Concr Res 2008;38:115-27.
6. Schneider M, Romer M, Tschudin M, Bolio H. Sustainable cement production-present and future. Cem Concr Res 2011;41:642-50.
7. Owens PL, Newman JB. Lightweight aggregate manufacture. In: Elsevier eBooks. Amsterdam: Elsevier; 2003. p. 1-12.
8. Ali MR, Maslehuddin M, Shameem M, Barry MS. Thermal-resistant lightweight concrete with polyethylene beads as coarse aggregates. Constr Build Mater 2018;164:739-49.
9. Allahverdi A, Azimi SA, Alibabaie M. Development of multi-strength grade green lightweight reactive powder concrete using expanded polystyrene beads. Constr Build Mater 2018;172:457-67.
10. Herki BA, Khatib JM, Negim EM. Lightweight concrete made from waste polystyrene and fly ash. World Appl Sci J 2013;21:1356-60.
11. Mastali M, Kinnunen P, Isomoisio H, Karhu M, Illikainen M. Mechanical and acoustic properties of fiber-reinforced alkali-activated slag foam concretes containing lightweight structural aggregates. Constr Build Mater 2018;187:371-81.
12. Chung SY, Abd Elrahman M, Stephan D, Kamm PH. The influence of different concrete additions on the properties of lightweight concrete evaluated using experimental and numerical approaches. Constr Build Mater 2018;189:314-22.
13. Shafigh P, Nomeli MA, Alengaram UJ, Mahmud H B, Jumaat MZ. Engineering properties of lightweight aggregate concrete containing limestone powder and high volume fly ash. J Clean Prod 2016;135:148-57.
14. Rahmani E, Dehestani M, Beygi MH, Allahyari H, Nikbin IM. On the mechanical properties of concrete containing waste PET particles. Constr Build Mater 2013;47:1302-8.
15. Záleská M, Pavlíková M, Pokorný J, Jankovský O, Pavlík Z, Černý R. Structural, mechanical and hygrothermal properties of lightweight concrete based on the application of waste plastics. Constr Build Mater 2018;180:1-11.
16. Alqahtani FK, Ghataora G, Khan MI, Dirar S. Novel lightweight concrete containing manufactured plastic aggregate. Constr Build Mater 2017;148:386-97.
17. Tang P, Brouwers HJ. The durability and environmental properties of self-compacting concrete incorporating cold bonded lightweight aggregates produced from combined industrial solid wastes. Constr Build Mater 2018;167:271-85.
18. Bogas JA, Cunha D. Non-structural lightweight concrete with volcanic scoria aggregates for lightweight fill in building’s floors. Constr Build Mater 2017;135:151-63.
19. Topçu İB, Uygunoğlu T. Effect of aggregate type on properties of hardened self-consolidating lightweight concrete (SCLC). Constr Build Mater 2010;24:1286-95.
20. Libre NA, Shekarchi M, Mahoutian M, Soroushian P. Mechanical properties of hybrid fiber reinforced lightweight aggregate concrete made with natural pumice. Constr Build Mater 2011;25:2458-64.
21. Grabois TM, Cordeiro GC, Toledo Filho RD. Fresh and hardened-state properties of self-compacting lightweight concrete reinforced with steel fibers. Constr Build Mater 2016;104:284-92.
22. Kayali O. Fly ash lightweight aggregates in high performance concrete. Constr Build Mater 2008;22:2393-9.
23. Erdogan ST. Determination of Aggregate Shape Properties Using X-ray Tomographic Methods and the Effect of Shape on Concrete Rheology. Austin: The University of Texas at Austin; 2005.
24. Nguyen LH, Beaucour AL, Ortola S, Noumowé A. Influence of the volume fraction and the nature of fine lightweight aggregates on the thermal and mechanical properties of structural concrete. Constr Build Mater 2014;51:121-32.
25. Lo TY, Cui HZ, Li ZG. Influence of aggregate pre-wetting and fly ash on mechanical properties of lightweight concrete. Waste Manag 2004;24:333-8.
26. Cui HZ Lo TY, Memon SA, Xing F, Shi X. Analytical model for compressive strength, elastic modulus and peak strain of structural lightweight aggregate concrete. Constr Build Mater 2012;36:1036-43.
27. Haque MN, Al-Khaiat H, Kayali O. Strength and durability of lightweight concrete. Cem Concr Compos 2004;26:307-14.
28. Bogas JA, Gomes A. Compressive behavior and failure modes of structural lightweight aggregate concrete-Characterization and strength prediction. Mater Des (1980-2015) 2013;46:832-41.
29. Neville AM. Properties of Concrete. Vol. 4. London: Longman; 1995. p. 1995.
30. Uysal H, Demirboğa R, Şahin, R Gül R. The effects of different cement dosages, slumps, and pumice aggregate ratios on the thermal conductivity and density of concrete. Cem Concr Res 2004;34:845-8.

31. Ke Y. Caractérisation du Comportement Mécanique des Bétons de Granulats Légers: Expérience et Modélisation (Doctoral Dissertation, Cergy-Pontoise); 2008.
32. Sengul O, Azizi S, Karaosmanoglu F, Tasdemir MA. Effect of expanded perlite on the mechanical properties and thermal conductivity of lightweight concrete. Energy Build 2011;43:671-6.
33. Liu MY, Alengaram UJ, Jumaat MZ, Mo KH. Evaluation of thermal conductivity, mechanical and transport properties of lightweight aggregate foamed geopolymer concrete. Energy Build 2014;72:238-45.
34. Hossain KM. Properties of volcanic pumice based cement and lightweight concrete. Cem Concr Res 2004;34:283-91.