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USE OF LIGHTWEIGHT MATERIALS FOR THE PRODUCTION OF LOW-DENSITY CONCRETE: A LITERARY REVIEW[1]

USO DE MATERIALES LIGEROS PARA LA PRODUCCIÓN DE HORMIGÓN DE BAJA DENSIDAD: UNA REVISIÓN LITERARIA

Liseth Díaz-Merino
Bachiller de en Ingeniería Civil, Estudiante de Ingeniería Civil, Universidad Señor de Sipán. Chiclayo, Perú
https://orcid.org/0000-0002-7339-9898
dmerinoliseth@crece.uss.edu.pe

Luis Fernando Altamirano-Tocto
Bachiller de en Ingeniería Civil, Estudiante de Ingeniería Civil, Universidad Señor de Sipán, Chiclayo, Perú
https://orcid.org/0000-0002-9126-8787
atoctoluisferna@crece.uss.edu.pe

Sócrates Pedro Muñoz-Pérez
Doctor en Gestión Pública y Gobernabilidad, Director de la Escuela de Ingeniería Civil, Profesor- Investigador, Universidad Señor de Sipán, Chiclayo, Perú
https://orcid.org/0000-0003-3182-8735
msocrates@crece.uss.edu.pe

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RESUMEN

A lo largo del siglo XX la industria de la construcción viene empleando grandes cantidades de hormigón, en consecuencia, ha aumentado la demanda de los agregados naturales, de manera que se hace necesario contrarrestar el uso de estos. Frente a tal contexto, el presente trabajo tiene como objetivo presentar una revisión literaria del uso de materiales ligeros para producir hormigón de baja densidad, el cual posee aislamiento térmico que se produce principalmente con agregados ligeros. En ese marco, se revisaron 52 artículos indexados entre los años 2017 y 2021 en la base de datos de Scopus. Los resultados revelaron que, empleando ceramsite de lodo como árido, se puede obtener una densidad de 1251 kg/m^3 y, con agregados de arcilla expandida, se puede obtener resistencias a la compresión desde 17.7 a 66.1 MPa. En conclusión, se logró determinar que con el uso de materiales livianos en la producción de hormigón se puede disminuir su densidad, además de contribuir en la reducción de daños que se generan al medio ambiente.

Palabras clave:
agregados ligeros, aislamiento térmico, hormigón de baja densidad, residuos.

ABSTRACT

Throughout the 20th century, the construction industry has been using large quantities of concrete. Consequently, the demand for natural aggregates has increased, making it necessary to counteract their use. In this context, this work aims at presenting a literature review of the use of lightweight materials to produce low-density concrete, whose thermal insulation is mainly made using lightweight aggregates. In this framework, 52 articles indexed between 2017 and 2021 in the Scopus database were reviewed. The results revealed that, by employing ceramsite sludge as an aggregate, a density of 1,251 kg/m3 can be obtained and, with expanded clay aggregates, compressive strengths from 17.7 to 66.1 MPa can be obtained. In conclusion, it was determined that the use of lightweight materials in concrete production can reduce its density, in addition to contributing to the reduction of environmental damage.

Keywords:
lightweight aggregates, thermal insulation, low-density concrete, waste.

INTRODUCTION

Concrete is the most widely used material in the construction industry. In 2015 alone, 20 billion tons were used worldwide. This material comprises conventional aggregates that correspond to between 55% and 88% of the total volume, and it is estimated that by 2023, its production will increase to 48.3 billion tones, which may lead to overexploiting the aggregate quarries (Pokorny, Ševcík, Šál & Zárybnická, 2021). Concrete is typically used in the construction of structures such as buildings, bridges, and water conservation projects (Ojha, Singh & Behera, 2021). Said structures, once they have fulfilled their life cycle, are destroyed and thrown away, generating great damage to the environment (X. Sun *et al.,* 2021).

Energy consumption has attracted considerable attention from Governments, industries, and the scientific community. From the starting point of a lack of available energy resources, different research projects have been made on efficient materials (Jones, Ozlutas & Zheng, 2017). In this context, many efforts have been made to study new engineering materials that can absorb energy, such as lightweight concrete, which represents a significant step toward reducing the amount of greenhouse gas emissions (Palanisamy *et al.,* 2020.

It is for this reason that countries with better economic positions and technology related to research have been implementing the use of light aggregates in concrete, seeking a construction material that looks to take care of the planet (Aley Kumar, Karthik & Mangala Keshava, 2020). This type of technology reduces environmentally harmful impacts, on being industrial or natural products that can be reused and replace conventional aggregates, as they perform similar roles to those in concrete (Kailash & Rashmi, 2018), and likewise generate alternative solutions for the lack of natural resources (X. Sun *et al.* 2021). In this way, it is possible to recycle waste materials, obtaining lightweight aggregates to thus manufacture environmentally friendly concrete (Hamidian & Shafgh, 2021).

Lightweight concrete, also known as "special low-density concrete", which has advanced thermal insulation, is mainly produced with lightweight aggregates or a cellular matrix (Y. Sun *et al.,* 2021). These comprise around 50% of the volume of concrete, while the material made from a cellular matrix is generally known as "foam concrete", due to the pores introduced by a foaming agent (Chung, Sikora, Stephan & Abd Elrahman, 2020).

Concrete with lightweight aggregates can be obtained naturally or by processing environmental and industrial waste. Thanks to the different useful properties of lightweight concrete as a construction material, it is becoming more widely known (Pateriya, Dharavath & Robert, 2021). Given its low density, it reduces the dead loads in constructions (Al-lami & Al-saadi, 2021), so this concrete can produce structural elements with a lower weight, which is why they improve the load capacity which, at the same time, enables them to be used in construction elements like load-bearing walls, as they are also an effective thermal insulation material (Appavuravther, Vandoren & Henriques, 2021). In this sense, the use of structural lightweight concrete leads to a lighter structure that offsets any lateral force provoked by an earthquake (Yinh *et al.*, 2021).

Ultimately, the main goal of using lightweight concrete is to simplify the design of structural elements to create sustainable infrastructures. Its application in construction reduces costs, facilitates the construction process, and has the advantage of being a relatively "green" construction material (A. Mohamed, E. Mohamed, Sang-Yeop, Pawel & Dietmar, 2019). Nowadays, there are different types of lightweight concrete, depending on the lightweight aggregate used, such as expanded clay, plastic, wood, tiles, as well as natural porous materials, like pumice, which are normally used as an aggregate in lightweight concrete mixes (Strzałkowski, Sikora, Chung & Elrahman, 2021). In the same vein, their traditional application in the construction industry is considered, for example, in masonry walls, as well as in different structural elements, such as lightened slabs and columns (Hücker & Schlaich, 2017).

Specifically, the purpose of this article is to present the literature review made on the use of lightweight materials that are capable of producing low-density concrete.

METHODOLOGY

This article falls within an exploratory experimental process, whose purpose is to analyze different articles from specialist journals on studies related to low-density concrete and lightweight materials, used in construction sites. In this way, a search was made on the Scopus database between 2017 and 2021, using the keywords in English, "lightweight materials in low-density concrete", and incorporating the Boolean operators "and", "or", "and not". With the operator "and", 154 articles were found, before then filtering by the areas of "Engineering", "Material Science", and document type, "article". This process resulted in 34 articles, out of which 7 were chosen. This was repeated with the operator "or", finding 33,368 documents. This was then filtered by area and document type, obtaining 7,456, from which

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Database	Year of Publication					
	2017	2018	2019	2020	2021	Total
Scopus	3	1	4	13	31	52
Total	3	1	4	13	31	52

Table 1. Distribution of articles references by year of publication and database. Source: Prepared by the authors.

Database	Keywords with Boolean operators	Documents Found	Search Years	Search Filters	Documents found using filters	Documents chosen
Scopus	(Lightweight AND materials) AND (low-density AND concrete)	158	2017-2021	Area: "Engineering"	34	7
				"Material Science"		
				Document type: Article		
	(Lightweight AND materials) OR (low-density AND concrete)	33368	2017-2021	Area: "Engineering", "Material Science"	7456	32
				Document type: Article		
	(low-density AND concrete) AND NOT (lightweight AND materials)	678	2017-2021	Area: "Engineering"	138	13
				"Material Science"		
				Document type: Article		

Table 2. Summary, criteria, and search results from the Scopus database. Source: Prepared by the authors

32 articles were chosen. Finally, with the operator "and not", 678 documents were found. These were then filtered once more by area and document type, ending with 138, of which 13 articles were chosen. This methodology is presented in greater detail in Table 1, Table 2, and Figure 1.

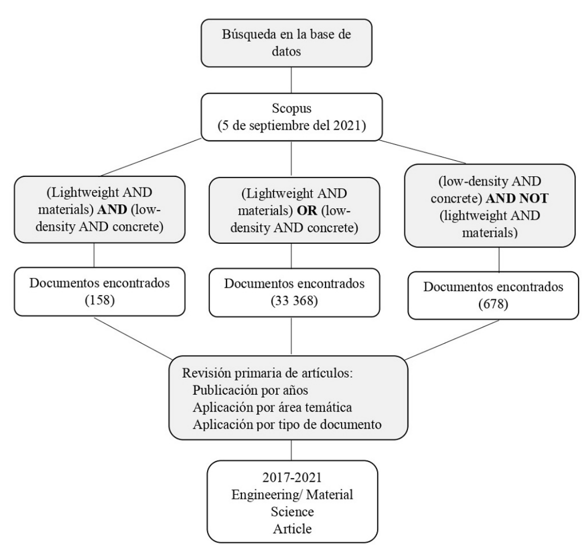

Figure 1. Article search in Scopus database. Source: Prepared by the authors.

RESULTS AND DISCUSSION

LIGHTWEIGHT MATERIALS

Lightweight aggregates are beneficial because they reduce the dead loads of a structure and provide internal curing to mitigate early cracking, while also reducing the effects of an earthquake (Muralitharan & Ramasamy, 2017). However, the dose of the mix and the handling of recently mixed lightweight aggregate concrete (LWAC) are not as simple as those of conventional concrete (J. Kim, Lee & Y. Kim, 2021).

The construction industry has a great impact on economic growth, but, at the same time, is known as one of the main consumers of natural resources and energy for the manufacture of raw materials around the world (Chung, Sikora, Kim, El Madawy & Abd Elrahman, 2021). Hence, the concentration in the implementation of waste and byproducts to substitute natural and manufactured materials is ever more important to support the concept of a green product (Moutassem, 2020).

Different types of materials have been used to produce lightweight concrete, such as lightweight

Type of concrete	Standard (ASTM)	Aggregate		Concrete		
		Sizes	Density (Kg/m3)	Types	Density (Kg/m3)	Compressive resistance (MPa)
Structural Concrete	C330	*Fine	* >1120	*Furnace slag	1360-1920	17-28
		*Coarse	* >880	*Pulverized ash		
		*Combination of fine and coarse Aggregate	* >1040	*Expanded clay		
				*Expanded slate		
				*Pumice		
				*Slag		
				*Limestone		
				*Diatomaceous		

Table 3. Summary of the different sizes of aggregates and types of concrete adding lightweight materials. Source: Maghfouri et al. (2021).

Type of Aggregate	Type of Cement	Aggregate Percentage	Compressive Resistance (MPa	Density (Kg/m3)	Water/ Cement Ratio	Reference
Plastic Lightweight A.	Ordinary Portland	75%	18	1900	0.5	(Alqahtani et al., 2021)
Expanded Polystyrene A.	Ordinary Portland	60%	30.53	1716	---	(Wibowo et al., 2021)
Expanded Polystyrene A.	CEM I 52.5N	15%	32	1900	0.39	(Rosca, 2021)

Table 4. Compressive resistance of artificial lightweight aggregates. Source: Prepared by the authors

aggregates. The exhaustive research of Maghfouri *et al*. (2021) focused on these different types of materials that can be used in LWAC with an apparently outstanding density.

There is a lot of research on materials that can be added to concrete for it to have a lower density (Zade, Bhosale, Dhir, Sarkar & Davis, 2021). For this reason, a systematic review of several studies on material behavior is presented below (Alqahtani & Zafar, 2020), for natural materials, artificial materials, or waste products used in lightweight aggregate concrete (Zeng, Sun, Tang & Zhou, 2020).

ARTIFICIAL LIGHTWEIGHT AGGREGATES

Plastic aggregate

The findings of Dielemans, Briels, Jaugstetter, Henke, and Dörfler (2021) indicated that the use of lightweight plastic aggregates in concrete structures leads to savings of up to 7.23% and 7.18% in the amount of concrete and steel. They also revealed that slab structures with vanes of between 4 and 5 m are the most benefitted from the use of this type of material.

Meanwhile, the analysis of Alqahtani, Abotaleb, and ElMenshawy (2021) states that, by replacing 75% of the volume of natural aggregates with recycled plastic and using ordinary Portland cement with a water-cement ratio of 0.5, the concrete reaches a compressive resistance (*f'c*) of 18 MPa and a density of 1900 kg/m^3.

Expanded polystyrene aggregate

The binding agent used in the research of Wibowo, Lianasari, Wiransya, and Kurniawan (2021) was ordinary Portland cement, with a 60% expanded polystyrene aggregate as a partial replacement of the fine aggregate in the volume. Here, an *f'c* of 30.53 MPa and a density of 1716 kg/m^3 were reached.

Another study made by Rosca (2021) revealed that with the use of CEM I 52.5N cement, this had a

Type of Aggregate	Type of Cement	Aggregate Percentage	Compressive Resistance (MPa	Density (Kg/m3)	Water/ Cement Ratio	Reference
Diatomaceous Earth A.	Ordinary Portland	40%	13.45	1290	0.55	(Hasan et al., 2021)
Palm Oil Clinker A	CEM I 42.5N	85%	35.56	1933	0.50	(Sarayreh et al., 2020)
Palm Almond and Whelk Shells A	Portland Ordinario	20% c/u	15	1900	0.60	(Ogundipe et al., 2021)

Table 5. Compressive resistance of natural aggregates. Source: Prepared by the authors

w/c ratio of 0.39 and a replacement of 15% of the thick aggregate volume for expanded polystyrene aggregate. It obtained an *f'c* of 32 MPa and a density of 1900 kg/m^3.

The information mentioned in the preceding paragraphs is summarized in Table 4, where it is possible to compare the results of the research of the aforementioned authors.

NATURAL LIGHTWEIGHT AGGREGATES

Diatomaceous earth aggregate

According to the study made by Vinod, Sanjay, Siengchin, and Fischer (2021), diatomaceous earth has a low density, which means that the material is useful to produce lightweight aggregates, specifically in the production of lightweight concrete.

In the work carried out by Hasan, Saidi, and Afifuddin (2021), seven different mixtures were made, from which it was observed that one in particular, had better results: a density of 1290 kg/m^3 and an *f'c* of 13.45 MPa, for a w/c ratio of 0.55, replacing 40% of the natural aggregates in weight.

Palm oil clinker aggregate

The lightweight concrete produced using a mix of waste materials has the advantage of protecting the environment and reducing costs in the construction industry.

In the research made by Sarayreh, Othman, Abdullah, and Sulaiman (2020), it was determined that with the substitution of 85% of coarse aggregate with palm oil clinker aggregate, and with the use of ordinary Portland cement CEM I 42.4 in a w/c ratio of 0.5, an *f'c* of 35.56 MPa is obtained at 28 days, and a density of 1933 kg/m^3.

On the other hand, Ogundipe, Ogunbayo, Olofinnade, Amusan, and Aigbavboa (2021) used 20% palm almond and 20 % whelk shells as a coarse aggregate and 60% natural coarse aggregate. Its w/c ratio was 0.60 and the cement used was ordinary Portland. The experimental results showed that its *f'c* was 15.3 MPa, and its density was 2040 kg/m^3.

Table 5 presents the results mentioned by the authors cited in this section

Expanded clay aggregate

Sindhuja and Bhuvaneshwari (2021) determined that using ordinary Portland cement, with a w/c ratio of 0.45, and with the substitution of 30% of the natural coarse aggregate for expanded clay aggregate to be used in columns with a maximum aggregate size of 15 mm, the lightweight concrete density is 1990 kg/m^{3,} and the *f'c*, at 28 days is 28.3 MPa.

Meanwhile, the article by Rahul and Santhanama (2020) examined concrete samples prepared with expanded clay lightweight aggregate whose maximum size was 10 mm. The binding agent used in the study was Portland cement, in mixtures of up to 30% substitution of coarse aggregate, which managed to reach an *f'c* of 25 MPa, with a w/c ratio of 0.40 and density of 2158 kg/m^3.

Similarly, Long (2020) used Portland cement type I and a w/c ratio of 0.40, obtaining an *f'c* of 19.7 MPa at 28 days, and a density of 1489 kg/m^3, on replacing 40% of the coarse aggregate in volume with expanded clay, whose aggregate size was 7 mm.

Meanwhile, Pontes, Bogas, Real, and Silva (2021) used Portland cement type I 42.5 R, with 15% expanded clay to replace the coarse aggregate, and a w/c ratio of 0.35, obtaining an *f'c* of 66.1 MPa and a density of 1920 kg/m^3.

Bicer (2021) applied expanded clay instead of conventional aggregates to produce low-density construction material. The samples were dried over 28 days at room temperature, and then the

Type of Aggregate	Type of Cement	Aggregate Percentage	Compressive resistance (MPa)	Density (Kg/m3)	Water/ Cement Ratio	Reference
Expanded Clay A.	Ordinary Portland	30%	28.3	1990	0.45	(Sindhuja y Bhuvaneshwari, 2021)
	Ordinary Portland	30%	25	2158	0.4	(Rahul y Santhanam, 2020)
	Portland Type I	40%	19.7	1489	0.4	(Long, 2020)
	Portland Type I	15%	66.1	1920	0.35	(Pontes et al., 2021)
	Portland Type I 42.5 R	10%	24.68	1420	0.5	(Bicer, 2021)
	CEM I 52.5	40%	17.7	1660	0.45	(Moreno-Maroto et al., 2019)

Table 6: Compressive resistance of expanded clay aggregates. Source: Prepared by the authors.

Type of Aggregate	Type of Cement	Aggregate Percentage	Compressive resistance (MPa)	Density (Kg/m3)	Water/ Cement Ratio	Reference
Pumice	Ordinary Portland	10%	27.1	---	0.45	(Ramanjaneyulu *et al.*, 2019)
	CEM IV 32,5 R	20%	24	1650	0.5	(Bicer y Celik, 2020)

Table 7. Compressive resistance of pumice aggregate. Source: Prepared by the authors.

measurements were made. To prepare the samples, Portland cement type I 42R was used, substituting 10% of the natural aggregates with expanded clay, at a w/c ratio of 0.5. As a result, the *f'c* was 24.68 MPa, the density was 1420 kg/m^3, and its conductivity coefficient was 0.215W/mK. All the samples had a water absorption rate below 30%.

Meanwhile, Moreno-Maroto, Beaucour, González-Corrochano, and Alonso-Azcárate (2019) replaced 40% of the coarse aggregate with expanded clay, using a size of 10 mm and Portland cement CEM I 52.5, for a w/c ratio of 0.45, obtaining an *f'c* of 17.7 MPa and a density of 1660 kg/m^3.

Below, Table 6 provides a summary of the results mentioned by the authors cited in this section.

Pumice aggregate

In their research, Ramanjaneyulu, Seshagiri Rao, and Desai, (2019) replaced coarse aggregate with pumice, whose optimal percentage was 10% of the normal weight aggregate in volume fractions, with a maximum size of 12 mm. In addition, ordinary Portland cement was used in a w/c ratio of 0.45, obtaining an *f'c* of 27.1 MPa, and a flexion resistance of 5.06 MPa.

On the other hand, the optimal pumice proportion used by Bicer and Celik (2020) in their study was 20% of the total volume, in replacement of the natural coarse aggregate. Pozzolanic cement, CEM IV / B (P) 32.5R was used, its w/c ratio was 0.50, with an *f'c* of 24 MPa, a density of 1650 kg/m^3, and thermal conductivity of 0.45W/(m.k).

The results mentioned by the authors cited in their research are contrasted in Table 7.

RECYCLED WASTE AGGREGATES

The use of waste materials and byproducts to substitute natural or manufactured resources is considered a practical way of obtaining green construction materials (Grzeszczyk & Janus, 2020).

Tile waste aggregates

Awoyera, Olalusi, and Babagbale (2021) stated that, with the substitution of 100% of the sand with tile waste, and using ordinary Portland cement, in a cement/pulverized fine tile aggregate ratio of 1:3, an *f'c* of 17.97 MPa is obtained at 28 days, lower values than the control mixture made in said research, whose density was 2363 kg/m^3 and whose flexion resistance was 1.26 MPa.

Type of Aggregate	Type of Cement	Aggregate Percentage	Compressive resistance (MPa)	Density (Kg/m3)	Water/ Cement Ratio	Reference
Tile Waste A.	Ordinary Portland	100%	17.97	2363	---	(Awoyera et al., 2021)
Crushed Brick A.	CEM-I 42.5R	10%	31.5	2255	0.6	(Tareq Noaman et al., 2020)
	Ordinary Portland	100%	45	1920	0.48	(Yang et al., 2020)
	CEM I 52.5 N	10%	33	1845	0.39	(Atyia et al., 2021)

Table 8. Compressive resistance of recycled waste aggregates. Source: Prepared by the authors.

Crushed clay brick aggregates
The use of a minimum content of natural materials in concrete production is the main concern of many researchers. This is apart from the fact that lightweight aggregate concrete is desirable due to its low weight and its modified physical properties (Yao *et al.*, 2021).

In this way, Tareq Noaman, Subhi Jameel, and Ahmed (2020) used Portland CEM-1 42.5 R cement, for a w/c ratio of 0.6. With an optimal percentage of 10% crushed clay brick aggregate as a partial replacement of natural sand, a density of 2255 kg/m^3 was obtained, an *f'c* of 31.5 MPa, and water absorption of 7.93%.

Meanwhile, Yang *et al.* (2020) proposed the use of crushed bricks as a coarse aggregate to produce a new lightweight concrete. Ordinary Portland 42.5 grade cement was used in the process, with a w/c ratio of 0.48. As a result, a compressive resistance (*f'c*) loss of 12% to 25% was achieved, and a flexion resistance, of 9% to 22% at 28 days of curing. The sample that behaved best was the one that used 100% of the crushed brick aggregate, showing an *f'c* of 45 MPa, a flexion resistance of 7.5 MPa, and a density of 1920 kg/m^3.

The experimental results of Atyia, Mahdy, and Elrahman (2021) indicated that crushed brick aggregates can be reused as a replacement for normal-weight aggregates to obtain lightweight aggregate structural concrete, using Portland CEM I 52.5 N cement, and replacing 10% of the cement with crushed clay brick aggregate, with a w/c ratio of 0.39. This led to an *f'c* of 33 MPa, a density of 1845 kg/m^3, and thermal conductivity of 0.6 W/m.k.

A summary of the densities and resistances of the recycled aggregates mentioned in the results of the aforementioned research can be seen in Table 8.

OTHER TYPES OF AGGREGATES

Slate ceramsite aggregate
To produce lightweight concrete specimens, G. Zhang *et al.* (2021) used ordinary 42.5 Portland cement with a w/c ratio of 0.47 and an optimal slate ceramsite proportion of 25% to replace coarse aggregate. In this way, on testing said specimens in the laboratory, an *f'c* of 28.1 MPa was obtained, and a density of 1907 kg/m^3.

Granulated rubber aggregate
Pongsopha *et al.* (2021) considered Portland Type I cement, a granulated rubber aggregate, and the replacement of 10% of the coarse aggregate with a w/c ratio of 0.35. Here, a compressive resistance and a density of 20.8 MPa and 1904 kg/m^{3,} were obtained, respectively, along with a flexion resistance of 4.38 MPa. The thermal conductivity was 0.485 W/m°C.

Mud ceramsite aggregate
This technology reduces the harmful impact of solid waste on the environment and addresses the scarcity of natural resources. The goal of the study was to develop lightweight green concrete that incorporates sludge ceramsite. (J. Zhang, Wang, Ge, Yang & Wei, 2021).

In the same vein, Xie, Liu, Liu, Wang, and Huang (2019) determined that, on using ordinary Portland cement with a w/c ratio of 0.36 and substituting river sand for 40% mud ceramsite aggregate in volume, there is an *f'c* at 28 days of 13.63 MPa, and a density of 1251 kg/m^3. For this, they state that mud ceramsite is a more environmentally respectful material than normal concrete for non-load-bearing structures.

Steel fiber aggregate
In the research of Wang, Liu, and Guo (2021), Portland P 52.5 cement was used, with a w/c ratio of

Type of Aggregate	Type of Cement	Aggregate Percentage	Compressive resistance (MPa)	Density (Kg/m3)	Water/ Cement Ratio	Reference
Slate Ceramsite A	Ordinary Portland	25%	28.1	1907	0.47	(J. Zhang et al., 2021)
Granulated Rubber A	Portland Type I	10%	20.8	1904	0.35	(Pongsopha et al., 2021)
Mud Ceramsite A	Ordinary Portland	40%	13.63	1251	0.36	(Xie et al., 2019)
Steel Fiber A.	Portland P · 52,5	2.25%	63.1	1800	0.23	(Wang et al., 2021)

Table 9: Compressive resistance of other types of aggregates. Source: Prepared by the authors

0.23, and a 2.25% steel fiber content in replacement of the coarse aggregate. Its *f'c* at 28 days was 63.1 MPa, and its density was 1800 kg/m^3.

A new summary of the densities and resistances of other aforementioned aggregates can be seen in Table 9.

CONCLUSION

The following has been concluded, based on the opinions of the different authors revised in this work, and from the results of their research on the use of lightweight materials in concrete:

There are lightweight materials that, on being used as aggregates in concrete, cause the latter to lower its density. As such, they can be used in building high-rise constructions, as they reduce the structure's weight and, at the same time, improve the compressive resistance of the concrete.

The expanded clay aggregate had the highest compressive resistance, of 66.1 MPa, compared to the other materials used in manufacturing low-density concrete.

The concrete with the lowest density was manufactured with mud ceramsite aggregate, reaching a density of 1251 kg/m^3 and compressive resistance of 14 MPa, on using 40% mud ceramsite aggregate and a water/ cement ratio of 0.36.

The use of lightweight materials in concrete production is an environmentally friendly alternative solution, as it allows broadening the range of aggregates that can be used in concrete with similar characteristics to those of the conventional version. In this way, these will be contributing towards reducing the impact that the overuse of conventional gravel-based aggregates may cause, and the production of the greenhouse effect, both so harmful to the environment.

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