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A review of thermo-mechanical behavior of lightweight concrete based on recycled plastic waste aggregates

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ABSTRACT

The rapid growth of the construction sector has driven researchers to develop innovative, environmentally friendly strategies. One such strategy is the incorporation of waste plastics into concrete production, which both enhances certain concrete properties and provides a viable approach for plastic waste valorization. Ethylene vinyl acetate (EVA) copolymer is a thermoplastic that has attracted growing research interest due to its flexibility, durability, and favorable thermal properties. In recent years, several studies have investigated the use of EVA waste aggregates in structural lightweight concrete. This study aims to synthesize the existing research on the use of EVA waste aggregates in concrete, providing a general overview of development in EVA waste aggregates concrete and examining its thermo-mechanical behavior in the hardened state. Results indicate that the partial replacement of natural aggregates with EVA waste improves thermal insulation performance, as demonstrated by a reduction in thermal conductivity. However, this improvement is accompanied by a reduction in mechanical performance, including flexural and compressive strengths. Overall, these results confirm that EVA waste aggregates can be used to produce lightweight concrete suitable for semi-structural application.

KEYWORDS

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Concrete
EVA waste
Sustainable Lightweight concrete
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1 Introduction

Concrete is the most widely used construction material globally, owing to a range advantageous property [1], including low cost, durability, strength, versatility in shape and size, and ease of handling [2, 3]. It is a composite material consisting of cement, coarse and fine aggregates, and water [4]. However, rapid urbanization and development have significantly intensified in the extraction and consumption of the natural used in concrete production [5]; aggregates alone account approximately constitute 65 to 80% of concrete's total volume. As a result, growing concern has arisen within the scientific community regarding the sustainability of this intensive exploitation [6].

Furthermore, population growth and increasing global consumption have led to a rapid rise in waste generation [5, 7]. A large proportion of this waste is non-biodegradable, resulting in server environmental pollution and ecosystem disruption [8]. In this context, the valorization of plastic waste has emerged as a particularly effective strategy for achieving economic and environmental benefits across a range of industrial sectors [9], with the construction industry offering promising opportunities for plastic waste utilization duo to these same benefits [10].

Within the construction sector, the production of lightweight building materials has emerged as a key avenue for the reuse of plastic waste [11]. Lightweight Aggregate Concrete (LWAC) is defined as concrete with a unit weight of less than 1840 kg/m³ [12]. The use of LWAC offers greater design flexibility, considerable cost savings, reduced dead load, improved structural response under cyclic loading, and lower foundation costs [13].

Among Plastic wastes, ethylene vinyl acetate (EVA) waste has been successfully incorporated into LWAC production [13, 14]. This is attributed to its ability to enhance the fracture toughness, waterproofing, and workability of concrete, which enable a reduction in the water/cement ratio, while also providing good thermal and acoustic insulation [8, 14]. However, polymer substitution significantly reduces compressive and flexural strengths, as well as the elastic modulus [8], this reduction is mainly attributed to the poor adhesion between the cement matrix and EVA waste aggregates [15].

In this context, the present paper synthesizes recent research on the incorporation of recycled EVA waste in concrete production and its effects on the thermo-mechanical behavior of the resulting lightweight concrete.

While numerous studies have investigated the impact of EVA waste on concrete [8, 16, 17] other researchers have conducted comparative analyses between EVA and alternatives waste materials. Santiago et al. [13] and Lima et al. [18] contrasted the influence of EVA with construction and demolition waste (CDW), whereas Gregorova et al. [19] compared the properties of EVA waste with those of plastic cable waste.

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2 Materials and methods

This review synthesizes the existing literature on the incorporation of EVA waste aggregates into concrete. It examines the production methods and fundamental physical and chemical properties of EVA waste aggregates, and critically assesses their impact on the microstructure, durability and thermo-mechanical behavior of the resulting hardened composites.

2.1 EVA plastic waste

EVA is a thermoplastic copolymer produced by copolymerization of the Ethylene a gas, with the vinyl-acetate monomers (Figure 1) [13, 16], in which the proportion of vinyl acetate typically ranges from 18% to 28% by weight [13].

Since the 1970s, EVA has been adopted in the footwear industry as a primary alternative to leather [13], valued for its high elasticity and its capacity to be sintered into porous structures. (Figure 2a) [16, 19].

Global footwear production has grown substantially in recent decades, rising from an estimated 2.3 billion pairs in 2005 [20] to reach 23.9 billion pairs in 2022, as shown in Figure 3 [21], with EVA waste accounting for nearly 14% of the materials used in production [13].

According to Lima et al. [18], an estimated 190400 tons of EVA waste are generated worldwide each year, of which it is estimated that only 5% is recycled, 15% is reused and 80% is landfilled [22].

To mitigate these ecological and economic impacts, the EVA waste was shredded to produce millimetric particles [8, 16, 19] (Figure 2b), which were then used as coarse aggregates in the production of lightweight concrete.

Technically, EVA waste aggregates is a highly effective modifier for cementitious materials, as it improves fracture toughness, waterproofness and workability [8, 23], ultimately allowing for a lower water/ cement ratio [24].

In Figure 4, chemical characterization via Fourier transform infrared spectroscopy reveals several characteristics bands, assigned to C-H stretching at 2917 cm^{-1} and 2848 cm^{-1}, C-O observed at 1300–1000 cm^{-1}, and CH3 bending at 1469 cm-1 [8, 16].

Santiago et al. [13], Highlight that EVA waste aggregates undergo surface smoothing at 69 °C, a temperature frequently reached within concrete in tropical regions, consequently, evaluating mechanical properties under thermal variation is necessary. Thermogravimetric analysis (TGA) was therefore conducted to characterize the polymer's degradation, revealing that the decomposition of EVA waste phases occurs within a temperature range between 250 and 410 °C (Figure 5).

Figure 6 illustrates the detailed procedure for incorporating EVA waste into concrete production. The process begins with the collection of EVA waste, followed by sorting and cleaning. The waste is then shredded and cut into small particles [13, 16, 18]. The resulting aggregates are then categorized based on size and may undergo optional treatment (chemical or heat) to enhance their adhesion to the cement matrix [24]. These plastic waste aggregates have been incorporated into concrete mixes as partial replacement, either as coarse and/or fine-aggregate, to varying extents [6]. The fresh concrete mixtures are cast into molds and cured under standardized controlled conditions for 28 days. Once the concrete has undergone the necessary curing process, the specimens are tested to investigate the impact of recycled aggregates on the properties of concrete. Specifically, the thermo-mechanical properties are evaluated including density, compressive strength, and thermal conductivity [6, 10, 13].

2.2 Physical properties of EVA waste aggregates

The physical properties of EVA waste used in concrete are presented in Table 1. There is a significant difference between the physical characteristics of EVA waste aggregates and those of conventional aggregates [6], as EVA waste exhibits a much lower specific gravity.

Baptista et al. [8] investigated the influence of EVA waste granulometry on concrete properties by comparing two distinct size ranges: millimetric and micrometric.

Table 1. Physical properties of EVA waste aggregates.

Reference	Particle size (mm)	Bulk density (Kg/m^3)	Specific gravity
Baptista et al. [8]	1-3.15	241.1	0.64
	< 526 Um	268.0	1.12
Santiago et al. [13]	9.5	240	0.24
Dulsang et al. [16]	4.5	145	-
Machado et al. [17]	-	249	-
Lima et al. [18]	9.5	100	0.24
Gregorova et al. [19]	4/8	104.41	-

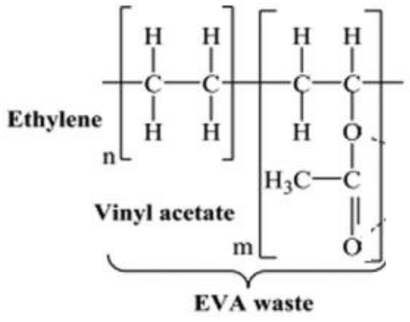

Fig. 1. Chemical composition of EVA waste [16].

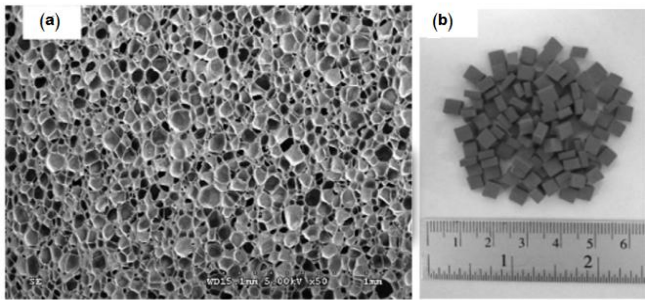

Fig. 2. The voids inside of EVA waste (a) and Shredded ethylene vinyl acetate (EVA) waste (b) [16].

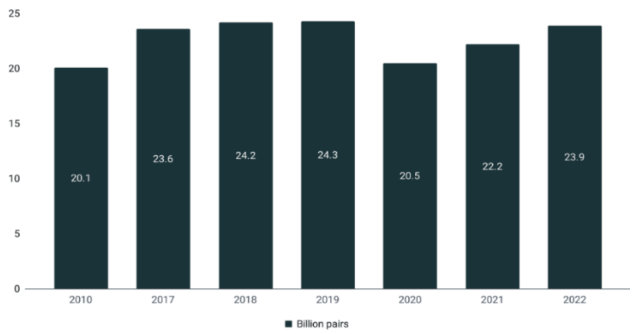

Fig. 3. Worldwide shoes (EVA) generation (2010-2022) [21].

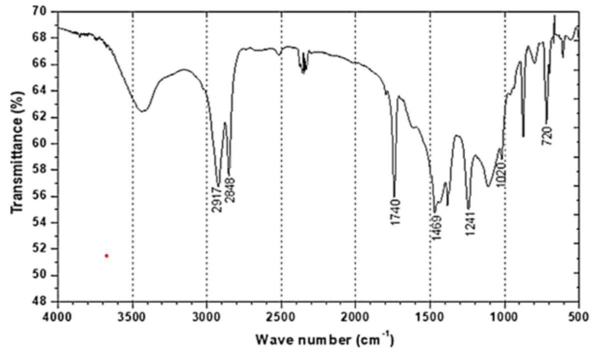

Fig. 4. FTIR results for EVA waste polymer [8].

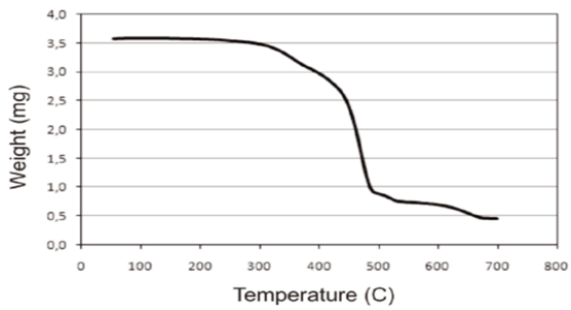

Fig. 5 Experimental TGA curve of EVA waste [13].

2.3 *Incorporation of EVA waste in concrete mixtures*

EVA waste was incorporated into concrete mixtures as detailed in Table 2. The preparation of the LWAC was based on two primary parameters: the substitution proportion of EVA waste (by weight or volume) and water /cement ratio (w/c) [8, 13, 19].

The mixes were specifically designed to achieve a target density between 800 and 1840 kg/cm³ [16], and compressive strength between 3.4 and 20 MPa [13, 16]. The specimens were cured for 48 hours in a moist environment. After demolding, they were cured in a humidity chamber at 23±2 °C and 100% relative humidity until reaching an age of 28 days [13, 16, 19].

the overall preparation procedure for lightweight aggregate concrete (LWAC) is illustrated in (Figure 6).

Table 2. The mix proportions.

Reference	Water/cement ratio	EVA %
Bapista et al. [8]	0.5	30, 50 and 70% Vol
Santiago et al. [13]	0.49 0.82	25, 50% Vol
Dulsang et al. [16]	0.45	3, 5, 7 and 10% Wt
Machado et al. [17]	0.564	10, 20 and 30% Vol
Lima et al. [18]	0.49 0.63 0.82	25 and 50% Vol
Gregorova et al. [19]	0.50	25, 50 and 75% Vol

3 Results and Discussion

The properties of concrete are evaluated in terms of density, mechanical strength and thermal conductivity. These performance criteria are assessed according to the standard procedures typically applied to conventional concrete at 28 days.

Table 3. Summary of density, compressive strength and thermal conductivity of concrete with EVA waste.

Reference	EVA %	density (kg.m^3)	Compressive strength (MPa)	Thermal conductivity (w/m·k)
Baptista et al. [8]	0-70%	Decreased	Decreased	-
Santiago et al. [13]	0-50%	Decreased	Decreased	-
Dulsang et al. [16]	3-10%	Decreased	Decreased	Decreased
Machado et al. [17]	0-30%	Decreased	Decreased	-
Lima et al. [18]	0-100%	Decreased then increased	Decreased	-
Gregorova et al. [19]	25-100%	Increased	Decreased	Increased

3.1 *Density*

Figure 7 and Table 3 illustrate the 28-day bulk densities of LWAC mixtures reported in past studies. As anticipated, the density of LWAC decreased with the increase EVA waste content [16, 18, 25]. This reduction is attributed to the internal voids within the EVA waste aggregates (Figure. 2.a) and to EVA's inherently low density [16]. Incorporating EVA waste as a lightweight aggregate can therefore lower concrete density and dead load by 48-66% [16], which helps minimize the risk of earthquake damage in buildings [8, 18, 25].

according to research [17], the addition of 30% of EVA waste as coarse aggregate to the concrete mix resulted in a 10.16% drop in density compared to the concrete mix without EVA waste. This was due to the low density of EVA waste in relation to the specific mass of the gravel, which presents a specific mass approximately 11 times larger than the EVA waste.

Another study [13] also noted that using 50% of EVA waste plastic aggregate reduces the density about 24%, resulting Reduction in the dead weight of a building or structure helps reduce the risk of earthquake damages [23].

Furthermore, Baptista et al. [8], who analyses the effect of granulometry by using mm EVA and µm EVA, find that, the coarser EVA (mm EVA) led to the highest density decrease (22% vs 18% for mm and µm EVA, 50% replacement) due to the larger empty volume left between the EVA particles.

On the other hand, when EVA mixtures of the two granulometries are used, the µm EVA particles will fill the space left free by the mm ones (sand and EVA particles) forming a more compact structure and leading to density values higher than those of mm EVA mortars.

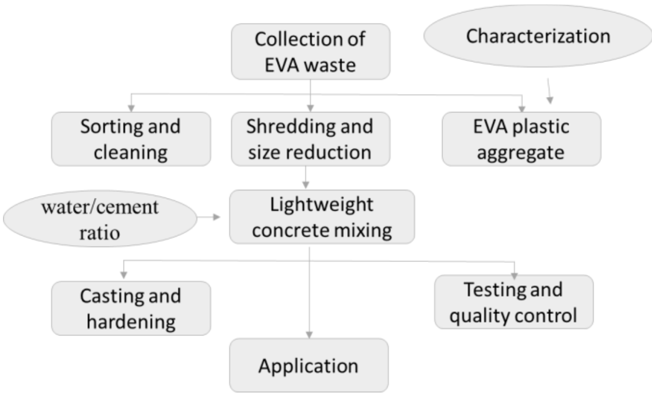

Fig. 6. EVA aggregates from waste into concrete.

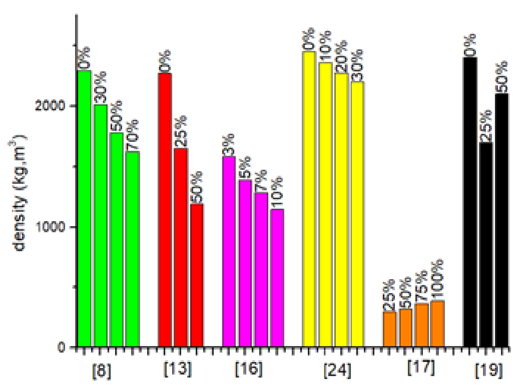

Fig. 7. Density of lightweight concrete as a function of EVA content : Baptista et al. [8], Santiago et al. [13], Dulsang et al. [16], Machado et al. [17], Lima et al. [18], Gregorova et al. [19].

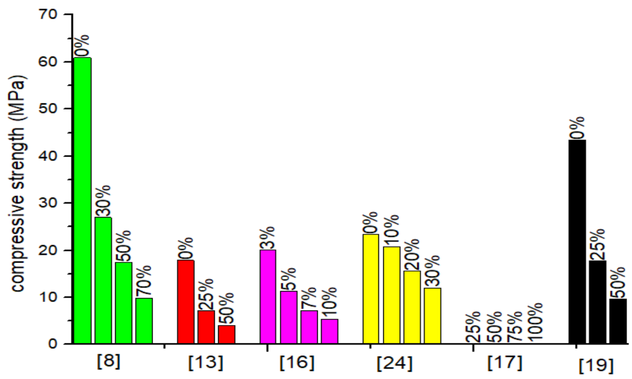

Fig. 8. Density of lightweight concrete as a function of EVA content : Baptista et al. [8], Santiago et al. [13], Dulsang et al. [16], Machado et al. [17], Lima et al. [18], Gregorova et al. [19].

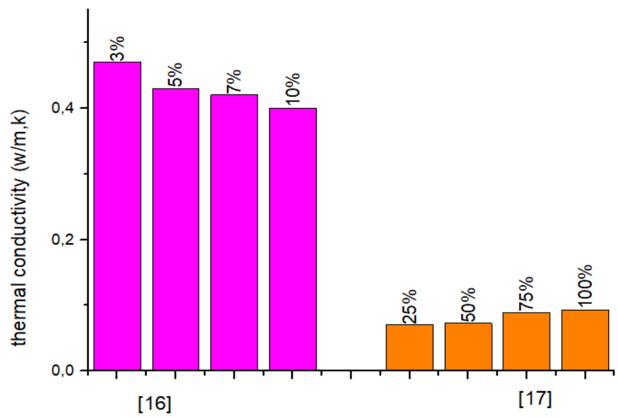

Fig. 9. Thermal conductivity of LWAC mixed with EVA waste at 28 days: Dulsang et al. [16], Gregorova et al. [19].

3.2 Compressive strength

Figure 8; Table 3 present the summary of the compressive strength results of past studies, reveal that the partial replacement of natural aggregates with EVA waste leads to a significant decrease in mechanical properties.

A Study [8] improve that the increased substitution of natural aggregates by mm EVA leads to a significant

decrease of the mechanical properties 71% for 50% EVA incorporation, and he find also that this loss of mechanical properties in less expressive when µm EVA is used than mm EVA, which suggest that the amount of incorporated EVA influences the mechanical properties differently for the mm and µm EVA.

Siddique et al. [26] found that the reasons for such strong mechanical properties losses lie (i) on the lower strength of plastic waste compared with natural aggregates ,thus favoring damage propagation; (ii) low plastic/matrix bonding strength, due to the intrinsic lack of chemical affinity between concrete matrix and the organic material, that prevents the formation of strong polymer-cement bonds (iii) air entrapment within the final concrete, due to the irregular shape and hydrophobic nature of plastic waste that promotes air bubble formation on the surface .

the loss of mechanical properties should also be ascribed to the higher volume of empty spaces generated in the case of mm EVA (µm particles may fill the spaces left between sand particles), and to the less homogeneous mixture obtained in the case of mm EVA [8], in good agreement with the results from other authors [13, 18, 19].

research [16] indicated the LWAC with 3 wt.% EVA waste could be classified as a structural lightweight concrete with the densities of 1440–1840 kg/m3 and the corresponding compressive strengths higher than 17.0 MPa. Furthermore, the LWAC with 5, 7 and 10 wt.% EVA could be classified as masonry concretes with densities of 800–1440 kg/m3 and compressive strengths of 3.4–17.0 MPa.

However, Lima et al. [18] observe that the w/c has an influence on the results: concretes with a w/c ratio equal to 0.82, the cement matrix around the aggregate particles has a lower compressive strength than the matrix of concrete with a w/c ratio equal to 0.49 that presented rupture by breakage of the aggregate.

Results of study [17], confirms that the EVA residue is the major cause of the reduction of resistance in the concrete [11], the greater the amount of EVA in the mixture the less the resistance of the concrete [27].

3.3 Thermal conductivity

Among the past studies, only two authors investigate on the thermal conductivity of the lightweight concrete, (Dulsang et al. and Gregorova et al. [16, 19]).

Figure 9, Table 3 presents the thermal conductivity results of LWAC.

The results indicate that thermal conductivity values generally tended to decrease as the EVA content increased [16, 19], the research [19] have found that the thermal conductivity values varied from 0.0603 to 0.0880 W/m·K . The study [16] indicates that the LWAC containing 10 wt.% EVA waste had the lowest thermal conductivity which was about one third of that of normal concrete.

According to Dulsang et al. [16], this reduction is attributed to the low thermal conductivity and density of EVA waste. Additionally, the enclosed pores within EVA waste also contribute to this effect, as they reduce overall thermal transfer due to the low thermal conductivity of air.

A relationship between thermal conductivity and density was established, where thermal conductivity tends to decrease with decreasing density [28].

Concrete with waste EVA can be used to produce lightweight, non-structural and highly thermal resistant concrete for use in insulation boards, partition walls, façade, etc., for energy conservation purposes [29].

4 Conclusion

This study provides an overview of the use of EVA waste aggregates in structural lightweight concrete. thermo-mechanical behavior of hardened concrete is reviewed. The result reveals a positive review of the incorporation of EVA waste aggregates in structural lightweight concrete, albeit with some limitations.

An estimation of 1904000 tons of EVA wastes are generated worldwide each year, with only 5% is recycled.

Density of LWAC decreased with the increase in EVA waste content, with decrease in the dead load, which helps minimize the risk of earthquake damage in buildings.

Partial replacement of natural aggregates with EVA waste leads to a significant decrease in mechanical properties.

Thermal conductivity values generally tended to decrease as the EVA content increased, which provided good thermal insulator.

The Use of EVA waste offers benefits not only technically but also environmentally and economically.

Based on these results, it can be concluded that utilizing EVA waste in concrete offers the possibility of providing this waste with a second life. Furthermore, LWAC based on recycled waste materials hold future potential combining multiple waste types, which may lead to improve thermal and mechanical properties.

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Declaration of Competing Interest

The authors declare that they have no competing interests or personal relationships that could have appeared to influence the content of this article.

References

[1] Y.H.M. Amran, R. Alyousef, H. Alabduljabbar, M. El-Zeadani, Clean production and properties of geopolymer concrete: A review, Journal of Cleaner Production 251 (2020) 119679. https://doi.org/10.1016/j.jclepro.2019.119679

[2] H. Tantawi, Introduction to Concrete Technology, Department of Civil Engineering, Fahad Bin Sultan University, 2015. https://doi.org/10.13140/RG.2.1.3219.9201

[3] X. Wen, A.M. Pagcaliwagan, H. Hou, X. Yin, Advancements in self-healing concrete: Material mechanisms, durability assessment, and implications for infrastructure lifecycle management, Alexandria Engineering Journal 131 (2025) 104–124. https://doi.org/10.1016/j.aej.2025.10.011

[4] R.H. Faraj, A.F.H. Sherwani, A. Daraei, Mechanical, fracture and durability properties of self-compacting high strength concrete containing recycled polypropylene plastic particles, Journal of Building Engineering 25 (2019) 100808. https://doi.org/10.1016/j.jobe.2019.100808

[5] B. Bhardwaj, P. Kumar, Waste foundry sand in concrete: A review, Construction and Building Materials 156 (2017) 661–674. https://doi.org/10.1016/j.conbuildmat.2017.09.010

[6] C.K.A. Uche, S.A. Abubakar, S.N. Nnamchi, K.J. Ukagwu, Polyethylene terephthalate aggregates in structural lightweight concrete: A meta-analysis and review, Discover Materials 3 (2023) 24. https://doi.org/10.1007/s43939-023-00060-8

[7] Y.A. Hajam, R. Kumar, A. Kumar, Environmental waste management strategies and vermi transformation for sustainable development, Environmental Challenges 13 (2023) 100747. https://doi.org/10.1016/j.envc.2023.100747

[8] M.C. Baptista, M. Da Luz Garcia, S.C. Pinho, M. Ascensão Lopes, M.F. Almeida, C. Coelho, C. Fonseca, Valorization of EVA waste from footwear industry as natural aggregates substitutes in mortar: The effect of granulometry, Journal of Material Cycles and Waste Management 23 (2021) 1445–1455. https://doi.org/10.1007/s10163-021-01222-7

[9] B. Haba, S. Djellali, Y. Abdelouahed, S. Boudjelida, F. Faleschini, M. Carraro, Transforming plastic waste into value: A review of management strategies and innovative applications in sustainable construction, Polymers 17 (2025) 881. https://doi.org/10.3390/polym17070881

[10] H. Altawaiha, A review on the utilization of E-plastic waste in concrete production: A step towards sustainability, Journal of Building Pathology and Rehabilitation 9 (2024) 131. https://doi.org/10.1007/s41024-024-00486-4

[11] E. Meglio, A. Davino, A. Formisano, Experimental tests on lightweight cement mortar and concrete with recycled plastic wastes, Buildings 13 (2023) 1181. https://doi.org/10.3390/buildings13051181

[12] T.Y. Shin, Y.H. Kim, C.B. Park, J.H. Kim, Quantitative evaluation on the pumpability of lightweight aggregate concrete by a full-scale pumping test, Case Studies in Construction Materials 16 (2022) e01075. https://doi.org/10.1016/j.cscm.2022.e01075

[13] E.Q.R. Santiago, P.R.L. Lima, M.B. Leite, R.D. Toledo Filho, Mechanical behavior of recycled lightweight concrete using EVA waste and CDW under moderate temperature, Revista IBRACON de Estruturas e Materiais (2009) 211–221. https://doi.org/10.1590/S1983-41952009000300001

[14] R. Siddique, J. Khatib, I. Kaur, Use of recycled plastic in concrete: A review, Waste Management 28 (2008) 1835–1852. https://doi.org/10.1016/j.wasman.2007.09.011

[15] O. Ünal, T. Uygunoğlu, A. Yildiz, Investigation of properties of low-strength lightweight concrete for thermal insulation, Building and Environment 42 (2007) 584–590. https://doi.org/10.1016/j.buildenv.2005.09.024
[16] N. Dulsang, P. Kasemsiri, P. Posi, S. Hiziroglu, P. Chindaprasirt, Characterization of an environment friendly lightweight concrete containing ethyl vinyl acetate waste, Materials & Design 96 (2016) 350–356. https://doi.org/10.1016/j.matdes.2016.02.037
[17] R.O. Machado, L.C.K.M. Pereira, E.B. Zanelato, A.L.F. Manhães, A.R.G. Azevedo, M.T. Marvila, J. Alexandre, S.N. Monteiro, L.T. Petrucci, Incorporation of EVA residue for production of lightweight concrete, in: Characterization of Minerals, Metals, and Materials, Springer, 2019, pp. 673–681. https://doi.org/10.1007/978-3-030-05749-7_67
[18] P.R.L. Lima, M.B. Leite, E.Q.R. Santiago, Recycled lightweight concrete made from footwear industry waste and CDW, Waste Management 30 (2010) 1107–1113. https://doi.org/10.1016/j.wasman.2010.02.007
[19] V. Gregorova, M. Ledererova, Z. Stefunkova, Investigation of influence of recycled plastics from cable, ethylene vinyl acetate and polystyrene waste on lightweight concrete properties, Procedia Engineering 195 (2017) 127–133. https://doi.org/10.1016/j.proeng.2017.04.534
[20] R. Shahin, T. S. [verify full surname], G. C. [verify full surname], Recycling of Footwear Products, Position Paper, Centre for Sustainable Manufacturing and Reuse/Recycling Technologies (SMART), Loughborough University, 2007.
[21] J.J. Andersen, Footwear Production Statistics, RunRepeat, 2023. https://runrepeat.com/footwear-production-statistics
[22] European Commission, Demonstration of a new business and consumption model for the circular economy in the footwear sector (LIFE KANNAGreen), LIFE Public Database.
[23] V. Balagopal, J.P. Raju, A.A. Kumar, M. Sajeev, P. Veena, Effect of ethylene vinyl acetate on cement mortar: A review, Materials Today: Proceedings (2023). https://doi.org/10.1016/j.matpr.2023.03.692
[24] S. Sasi, P. Joseph, R. Haigh, M. Sandanayake, Z. Vrcelj, E. Yaghoubi, A review on the effects of waste textile polymer fiber on concrete strength: Exploring the key parameters, Buildings 14 (2024) 1486. https://doi.org/10.3390/buildings14051486
[25] V. Gregorova, S. Uncik, Characterization of lightweight concrete produced from plastics waste—Polystyrene and EVA, Applied Mechanics and Materials 861 (2016) 24–31. https://doi.org/10.4028/www.scientific.net/AMM.861.24
[26] R. Siddique, J. Khatib, I. Kaur, Use of recycled plastic in concrete: A review, Waste Management 28 (2008) 1835–1852. https://doi.org/10.1016/j.wasman.2007.09.011
[27] Z.Z. Ismail, E.A. Al-Hashmi, Use of waste plastic in concrete mixture as aggregate replacement, Waste Management 28 (2008) 2041–2047. https://doi.org/10.1016/j.wasman.2007.08.023
[28] P. Sukontasukkul, Use of crumb rubber to improve thermal and sound properties of pre-cast concrete panel, Construction and Building Materials 23 (2009) 1084–1092. https://doi.org/10.1016/j.conbuildmat.2008.05.021
[29] S.I. Basha, M.R. Ali, S.U. Al-Dulaijan, M. Maslehuddin, Mechanical and thermal properties of lightweight recycled plastic aggregate concrete, Journal of Building Engineering 32 (2020) 101710. https://doi.org/10.1016/j.jobe.2020.101710