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A Review on Sustainable Disposal of Plastic Waste by Integration in Construction Materials

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Abstract Over the last decades, plastic waste (PW) has increased exponentially and has become a serious threat to our planet, aquatic system and human health. Recycling or reusing PW in producing ecofriendly materials is an efficient solution to reduce plastic pollution and to minimize the depletion of raw materials as well. Previous studies have shown promising potentials of using PW in the construction sector, such as binder, aggregate, or substitute of cement and sand in concrete, brick or mortar. Laboratory results indicate that implementing plastic waste as aggregates in cement composites obtains higher thermal resistance and acoustical performance. However, a reduction in the compressive strength has been noticed with the increase of the PW content. Therefore, this study attempts to identify the optimum acceptable plastic waste content to be involved in the construction material in order to enhance its thermal resistance without jeopardizing the compressive strength. The aim of this study is achieved through a systematic review identified by keywords. Papers that did not include plastic waste reuse in construction material were eliminated. The inclusion criteria were based on the latest studies from 2012 that investigated the impact of plastic waste on thermal conductivity and compressive strength. A comparative analysis is then conducted on the eligible papers focusing on the used type, particle size and percentages of the applied PW and the impact on the thermal conductivity and the compressive strength. This review presents possibilities of reusing plastic waste to develop lightweight composites with better thermal capabilities and acoustical performance which enhance the building energy performance and create a more ecofriendly and sustainable environment. However, only a limited amount of plastic is allowable to be used to avoid the deterioration of the compressive strength.

Keywords Plastic Waste, Recycling, Construction Material, Sustainability

1. Introduction

Plastic is one of the most consumed materials and is involved in various applications due to its significant characteristics, its lightweight, flexibility, durability, thermal properties, chemical resistance, and cost efficiency. Generally, plastics are categorized into two main groups according to their chemical structures and reactions to heat: thermoplastics and thermosetting plastics. Thermoplastics are constantly reversible; they soften when heated and harden when cooled and are able to be recycled, reshaped and remolded. They present about 80% of the produced plastic, the most common types are: polyethylene terephthalate (PET), high-density polyethylene (HDPE), low-density polyethylene (LDPE), polyvinyl chloride (PVC), polypropylene (PP) and polystyrene (PS). In contrast, Thermosets are irreversible; they harden once they cooled. Hence, they are not able to be reshaped or remelted. Examples of thermosets plastics are: teflon, polyurethane foam, bakelite, polycarbonate, melamine and nylon [1]. HDPE, LDPE, PET, PP and PS are most types found in wastes [2].

Industrialization, urbanization and population growth are main factors for boosting plastic production [3]. The United Nations reported that the world produced over 400 million tons of plastic in 2018 which increased by 2.5% in 2019. Despite the low biodegradability of plastics, only a limited percentage is being recycled or burnt and the rest ends up in landfills. The UNEP stated that billion metric tons of plastic waste will cover landfills by 2050 [4]. Therefore, managing plastic waste and searching for innovative sustainable alternatives for reusing it, is imperative and should become the world's concern. Large scale of waste should be converted to a valuable ecofriendly product with a long lifespan to overcome this crisis. Hence, reusing plastic waste by employing it in construction material is a sustainable solution that will save our environment [5].

Previous studies developed different methodologies to integrate recycled plastics in producing ecofriendly building materials. Plastics have high thermal resistance which may improve the thermal performance of building materials if incorporated properly [6]. However, articles showed how plastics can affect the compressive strength of the material. Therefore, adjusting the content of plastic waste with regard to the compressive strength is challenging. This article addresses opportunities for sustainable disposal of PW by its integration in the construction industry. A literature review is conducted aiming to identify the relation between compressive strength, thermal conductivity, bulk density and plastic waste content in concrete, bricks and mortar.

2. Methodology

The research methodology was based on a systematic review using the most relevant keywords to the topic (i.e., Plastic waste, construction material, building envelope, thermal conductivity, and compressive strength). Articles that are irrelevant not based on reliable source or old were excluded. Eligible articles were identified through the title and abstract screening. A total of 55 articles were then comprehensively reviewed for inclusion. The inclusion criteria were based on the year of publications from 2012 till 2022 and the articles that implemented an empirical study to investigate the impact of plastic waste on the compressive strength and thermal conductivity of brick, concrete and mortar. Finally, 24 articles were included for further investigations. According to the literature conclusion, the research conducted an analytical deductive method to create guidelines for the use of plastic waste in different applications. The relevant data were summarized, and the outcomes were analyzed and compared.

3. Applications of Using PW in Concrete Production

Concrete is one of the commonly consumed construction materials. It consists of cement, water and two types of aggregates: coarse aggregates (gravel or crushed rocks) and fine aggregates (sand). Generally, aggregates form 65 to 85% of the concrete composite and are mainly responsible the for the concrete's mechanical, thermal and physical performance [7]. Partial substitution of aggregates with plastic waste will not only decrease the burden of plastic waste on the environment, but also decreases the depletion of natural resources like sand [8]. Replacing cement with PW will reduce CO_2 emissions that are released during cement production as well as cost [9]. While recycling one kg of plastic produces about 0.17kg of CO_2, manufacturing one kg of cement produces 0.66 to 0.82 kg of CO_2 [10].

Plastic waste may be integrated in the building materials in two forms: plastic aggregate (PA) and plastic fibers (PF). PAs are used to substitute coarse and fine aggregates. Plastic fiber (PF) can be used in fiber-reinforced concrete (FRC) and replace steel fiber as reinforcement to improve some of the concrete's properties like corrosion resistance, flexibility, and durability. However, partial replacement of aggregates or cement with PW affects the thermomechanical properties of the concrete. According to ASTM C90, the load-bearing wall unit must have a minimum compressive strength of 17 MPa [11].

3.1. Partial Replacement of Coarse Aggregates with PW

Thakur et al. investigated the partial weight replacement of coarse aggregates in concrete blocks with shredded waste of polyethylene terephthalate (PET). Different percentages (2.5%, 5%, and 7.5%) were used to substitute coarse aggregates to examine their impact on the mechanical and thermal properties in respect to the reference concrete mix. Sample A is the control sample; the coarse aggregates were substituted with 2.5%, C with 5% and D with 7.5% PET. Findings show that the higher the plastic waste content, the lower the compressive strength, thermal conductivity as well as the bulk density. Figure (1) shows the impact of the amount of PET on the compressive strength and thermal conductivity. The compressive strength of the control sample recorded 31 MPa after 28 days, 20 MPa for sample B 20MPa, 18MPa for C and 14 MPa for D.

Therefore, C and D do not belong to M20 concrete as their strength is lower than 20MPa. However, composite C falls under lightweight concrete because its compressive strength exceeds 17MPa. The thermal conductivity of the control mix was 1.8 W/mk and dropped to 1.38 W/mk, 1.15 W/mk and 0.7 W/mk for the 2.5 %, 5% and 7.5% sample, respectively. By replacing 5% PET, the volumetric density decreased by 20%, from 2500 kg/m^3 to 1920kg/m. This is due to the lower bulk density of plastic aggregates than conventional aggregates. Hence, this study determines the possibility of developing lightweight concrete with enhanced thermal resistance by applying plastic waste [11].

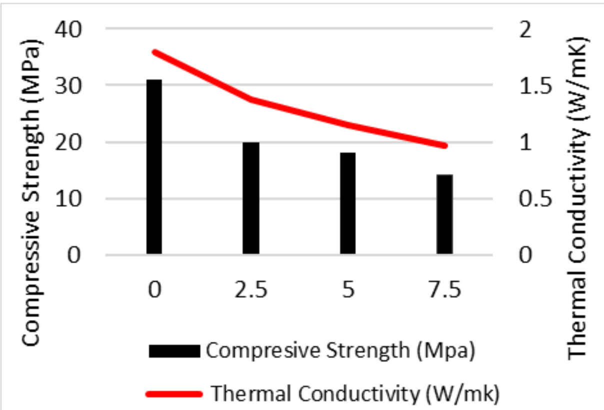


Figure 1. Compressive strength & thermal conductivity of concrete with PET

3.2. Partial Replacement of Fine Aggregates with PW

Almeshal et al. investigated the physical and mechanical properties of 6 concrete mixtures using granulated PET as a partial substitution (0%, 10%, 20%, 30%, 40% and 50%) of sand. The findings showed a decrease in the density with the increase of the plastic content. The density of the reference mix was 24.02 K N/m^3 (2450 kg/m^3) and dropped to 22.51 K N/m^3 (2295.38 kg/m^3), 19.33 K N/m^3 (1971.11 kg/m^3) and 16.42 K N/m^3 (1643 kg/m^3) with10%, 30% and 50% PET replacement, respectively. The measurements of the compressive strength, as illustrated in Figure (2), indicate a decrease with the increase of PET ratio. The reference sample obtained a compressive strength of 35.6MPa at the 28th curing age. The replacement of 10% and 20% PET reduced the compressive strength slightly. Although the 30% replacement reduced the compressive stress to 24.7 MPa, it still meets the code standards. A significant reduction was noticed at 40% and 50 % ratio, the compressive strength dropped by 60% and 90%, respectively. The main reason for this drop is caused by the lowered bond between the plastic and cement with the increase of the plastic content. [12]

3.3. Partial Replacement of Cement with PW

Also replacing cement with plastic waste showed potentials in enhancing the thermal conductivity. Abdelawab's et al. evaluated the thermal conductivity of concrete blocks after partially substitution of cement with melted plastic bags. By comparing the thermal conductivity of the sample including 33% and 66% plastic with the control sample, it decreased by 16%, from 1.70 W/mk to 1.43 W/mk [8].

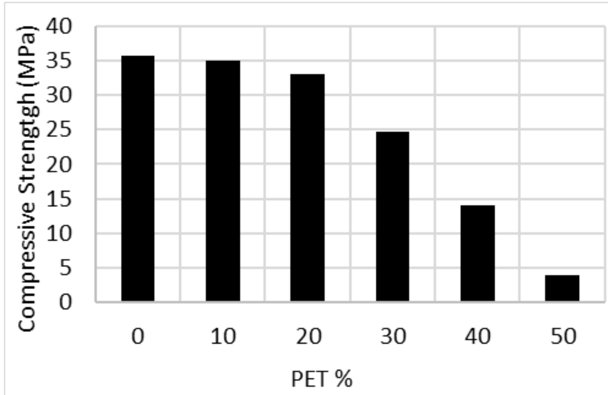


Figure 2. Compressive strength of concrete with PET

4. Applications of Using PW in Brick Production

Generally, there are many types of bricks, such as cement brick, clay brick and sand brick. Cement brick has the greatest impact on global warming in regard to other brick types. Although the phase of burning is missing during manufacturing process, it is not environmentally friendly due to the greenhouse gas emissions that are released during production. On the other hand, the clay brick or red brick causes the greatest harm to human health and depletes natural resources [13].

The German Earth Building Standards DIN 18945 classified bricks into three classes based on their compressive strength: Bricks with a mean compressive strength value between 2.5 and 3.8 MPa, referred to as Earth Blocks Class 2 (EB2). These can be used as partitions, sheds or in low height buildings with low loads. Earth Blocks Class 3 (EB3) are those with a mean compressive strength value between 3.8 and 5MPa. These can be used as non-load bearing self-supporting walls. Bricks with a mean compressive strength value above 5 MPa are referred to as Earth Blocks Class 4 (EB4) and can be used as inner walls and load-bearing walls of low-rise and middle-rise buildings [14].

4.1. Cement Brick with PW

Mondal et al. introduced a study to examine the integration of waste plastic in fly ash bricks. Different amount (0-10%) and types of plastic waste (polystyrene, polycarbonate and a mix of different thermoplastics) were used as a partial replacement of sand. All samples consist of 15% ordinary Portland cement (OPC), 15% fly ash and the rest sand with a particle size of 2 mm and certain amounts of plastic waste. The water was added with an amount of 25% of the dry mix. The samples were cured for 28 days under water and then divided into three sets. One set is baked at 90°C, another at 110°C and the last remained unbaked. The best results belonged to the unbaked set; hence Figure (3) presents the compressive and thermal conductivity of unbaked bricks.

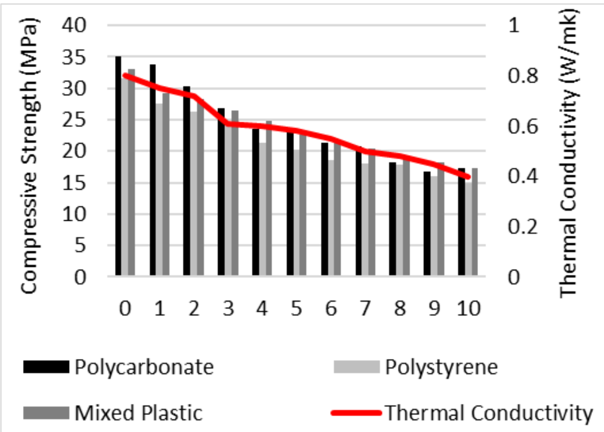
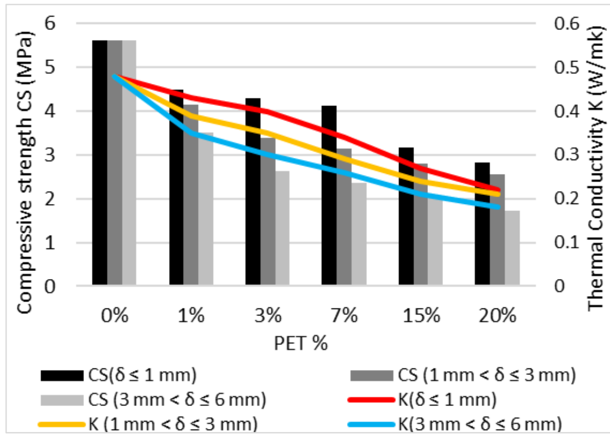


Figure 3. Compressive strength & thermal conductivity of cement brick with PW

The developed ash brick containing 10% of mixed plastic waste showed better results when compared with conventional types of bricks. Fired clay brick obtains a compressive strength between 15 and 20 MPA, fly ash brick between 11 and 19 MPa, while the plastic fly ash brick 17 MPA which still satisfies the recommended standards for loadbearing. In addition, it showed a lower thermal conductivity and bulk density. For instance, the bulk density of the unfired samples without plastic was 2.06g/cm^3 and dropped to 1.6g/cm^3 by adding 10% of mixed plastic to the composite. Changing the type of plastic waste barely affected the thermal conductivity values. Nevertheless, the amount of plastic waste is the main attribute that affects the results significantly. Increasing the percentage of plastic waste decreases the thermal conductivity which may improve the building energy performance. Therefore, integrating any type of thermoplastic waste in brick manufacturing with certain limits is an efficient solution and will affect circular economy [15].

4.2. Clay Brick with PW

Another study by Limami et al. evaluated the effect of different types, amounts and sizes of PW on the thermomechanical properties of unfired clay brick. HDPE and PET have been added with different substitution by weight (0%, 1%, 3%, 7%, 15% and 20%) and grain sizes ($\delta \leq 1$ mm; 1 mm $< \delta \leq 3$ mm and 3 mm $< \delta \leq 6$ mm). During preparation, they used a technique that improved the adhesion between the additive polymer and clay. The technique is called melt compounding technique that creates a homogenous mix between the components and increases the interactions between their surfaces through mixing the ingredients under a constant temperature of 300°C for 15 minutes. The results in Figure (4a-b) show, the smaller the grain size and the lower the plastic waste amount, the higher gets the compressive strength. In contrast, the larger the grain size and the higher the plastic waste amount, the lower gets the thermal conductivity.



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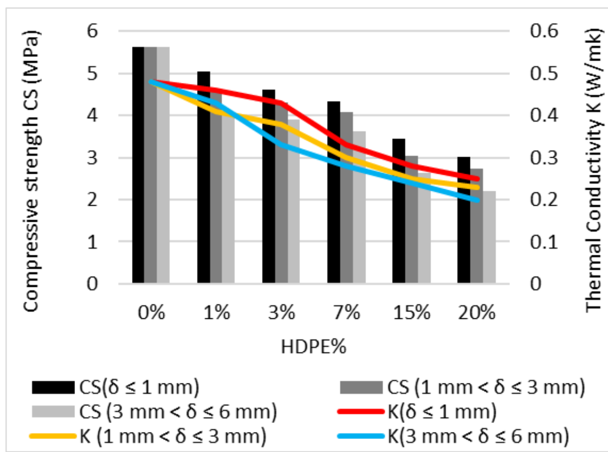

b)

Figure 4. Compressive strength & thermal conductivity of unfired clay with a) PET and b) HDPE

Figure (5) compares the results of HDPE and PET unfired clay brick for the smallest grain size. It is observed that samples with PET addition have lower compressive strength than with HDPE, but better thermal performance, as shown in Figure (6). This is due to the lower thermal conductivity value and lower compressive strength of PET than HDPE. Hence, the sample with the 7% HDPE was selected as the optimum sample when referring to the earth building code requirements DIN 18945 [16].

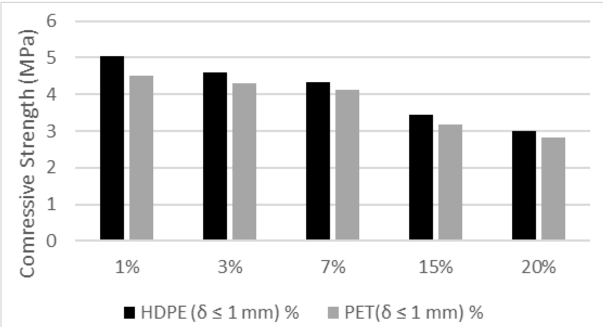

Figure 5. Comparison of compressive strength of unfired clay brick with HDPE and PET

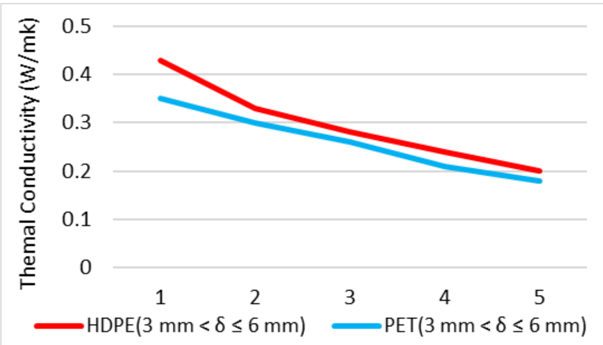

Figure 6. Comparison of thermal conductivity of unfired clay brick with HDPE and PET

4.3. LDPE Sand Blocks with PW

Kumi-Larbi et al. produced sand blocks using LDPE waste as a binder. LDPE was melted and mixed with sand without water addition. They studied the influence of sand particle size and plastic to sand ratio on the thermomechanical behaviour of the blocks. Four different sand size particles (d) were used, 0.25 mm, 0.75 mm, 1.68 mm and 3.55 mm. Unexpectedly, the thermal conductivity of LDPE-bonded sand showed a result of 1.72 W/mK, which is higher than concrete and cement mortar. A clarification for this could be, the reduced air voids and porosity in the LDPE-bonded sand samples. It was observed that the higher the sand particle size, the lower gets the compressive strength and density, due to the increase of air voids that are created. The plastic to sand ratio affected the compressive strength as well; the higher the sand, the higher gets the compressive strength till the sand reaches 75% of the composite. Increasing the sand amount more than 75% affects the compressive strength negatively, because minimizing the volume of LDPE binder reduces the coating of sand grains and the bond between them. The optimum compressive strength was achieved with 75wt% of sand, due to the decrease of porosity, which is 27.3 MPa. Figure (7) shows the impact of the sand particle size on the compressive strength of the sample with 75% sand. Their results indicate a strong and durable composite that behaves similar to asphalt in compression. The LDPE-sand blocks can be applied in paving or roofing tiles and wall portions [17].

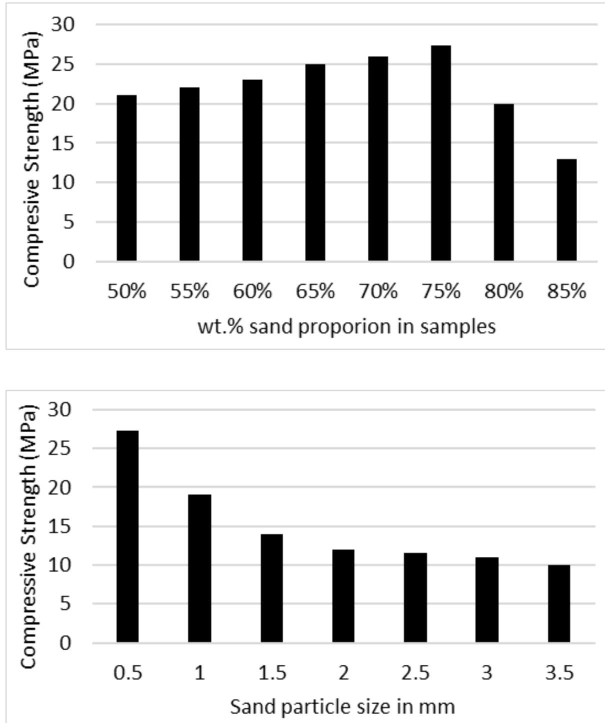

Figure 7. Compressive strength of unfired brick with different a) sand % b) sand size

5. Applications of Using PW in Mortar Production

Mortar is a composite of lime, Portland cement, water and sand. There are five types of mortar: M, S, N, O, and K, based on its bonding properties, flexibility, and compressive strength [18].

5.1. Partial Replacement of Cement in Mortar with PW

In the study of Attache et al. polyethylene (PE) was minced to partially replace Portland cement in mortar. First, they examined the degradation of HDPE when exposed to temperature. Five different mortar types of composites were prepared using superplasticizer to reduce the water demand. All mortars experienced an increase in their compressive strength by age due to hydration; however the existence of HDPE slows down the hydration process. Comparing 2% HDPE and that of the 6% at day 7, it is noticed that the compressive strength decreases from 12.58 MPa to 8.46 MPa, which is 32.74%. The same occurs when comparing 4% and 6% at day 14, the compressive strength is 16.79 MPa and 12.24 MPa, respectively, it decreased with 27.10%. Comparing the compressive strength of the 6% HDPE after 7 days and 28 days, 40% increase has been noticed. In terms of the tensile strength, the findings show an increase for all mortars containing HDPE compared to that of the reference sample.

Even the bulk density is affected; it decreased from 2.27 to 2.05 g/cm^3 by adding 6% of HDPE. The density is directly related to the thermal conductivity, the lower the density, the lower the thermal conductivity. Figure (8) shows the effect of HDPE content on the thermal conductivity and compressive strength [19].

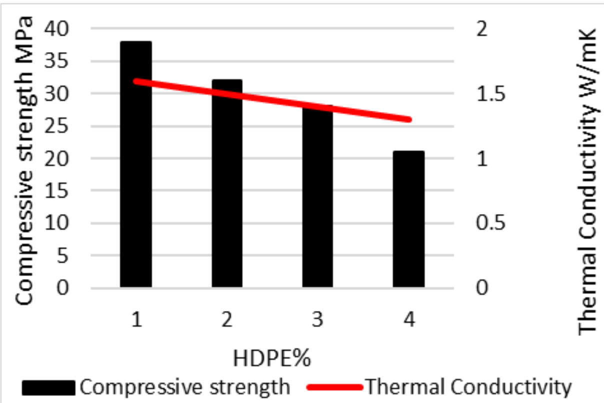

Figure 8. Compressive strength & thermal conductivity of mortar with HDPE

5.2. Partial Replacement of Sand in Mortar with PW

Another study was carried out by Acui et.al aiming to develop ecological mortar provided with PVC waste. Four samples were prepared with cement, lime, water, sand and 8mm minced PVC waste to substitute sand. They used PVC with a density of 500kg/m^3 with four different percentages (0%, 25%, 50% and 100%). PVC was minced to a size of maximum 8 mm and a density of 500kg/m^3.

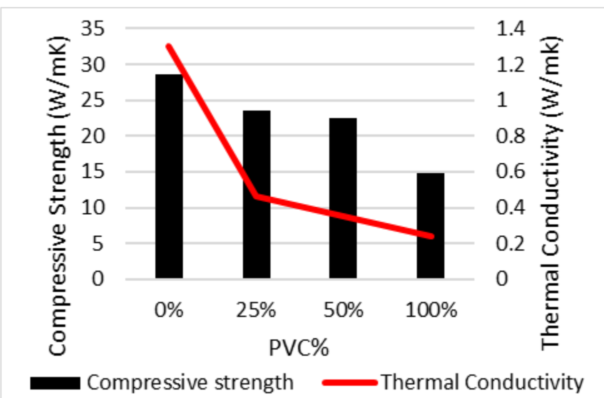

Figure 9. Compressive strength & thermal conductivity of mortar with PCV

The mortar composite without PVC can be categorized as plastering mortar class CSIV and masonry mortar class M20 based on its compressive strength, 28.6MPa. According to its density, it falls under the category of heavy mortar (>1800 kg/m^3). The results of the thermal conductivity in Figure (9) shows a significant decrease by replacing 25% sand with PVC waste; it is being reduced by 65% in comparison to the control mix. A 73% reduction is noticed with 50% replacement. The lowest k value is achieved by replacing the entire sand volume with PVC. This study demonstrates the potential of developing ecological mortar provided with PVC waste that can be used as a building material. Sample 2 with 25% replacement of sand obtained the best results in terms of compressive strength (≥ 6 N/mm2) and adhesion. It can be used as masonry mortars or plastering mortar. The mortar with 50% sand replacement can be classified as M20 and the one with 100% replacement as class M12.5, that can be used as paving [20].

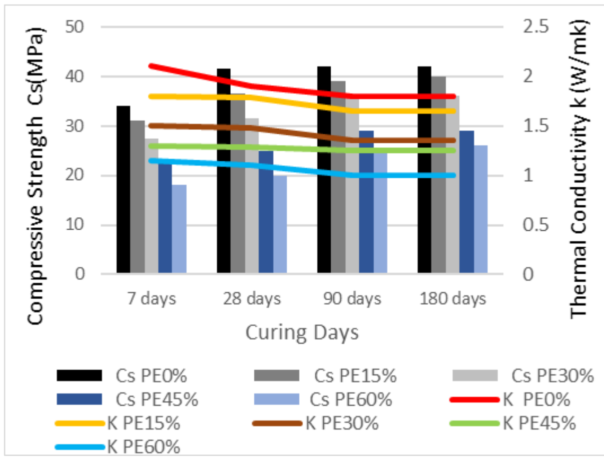

Figure 10. Compressive strength & thermal conductivity of mortar with HDPE

Another research by Badache et al. studied the effect of the partial replacement of HDPE with sand in mortar composites. Five samples were prepared using Portland limestone cement, sand and HDPE with different percentages (0%, 15%, 30%, 45% and 60%) for the same volume. The water/cement (W/C) ratio was 0.5 and the size of the HDPE particles remained constant in all composites. The control sample has a density of 2100 kg/m^3, this value was decreased to 2000kg/m^3 by replacing sand with 15% HDPE. By 60% replacement the density reached 1577 kg/m^3, which is almost 25% lower than the control sample. Regarding the compressive strength, Figure (10) shows, a decrease of 38% by adding 60% HDPE instead of sand at different ages. Readings of the thermal conductivity were taken at room temperature at different ages. By age the conductivity is lowered for all samples, due to the stored water in the pores that evaporates by age. The findings show a decrease of thermal conductivity with the increase of HDPE amount. The sample with the 60% HDPE replacement recorded the lowest thermal conductivity (1W/mK), because HDPE has a lower thermal conductivity (≈0.4 W/mK) than pure sand. The study indicates that after 90 days all composites have constant thermal conductivity.

By comparing the results with the reference sample after one year the results showed a reduction of 10%, 20%, 31% and 41%, for the 15%, 30%, 45% and 60% HDPE replacement, respectively.

In addition, ductility, dynamic modulus of elasticity and sound absorption has been tested on the 60% HDPE sample and compared to the reference mix. The laboratory tests showed a higher acoustic insulation, higher ductility, and lower dynamic modulus of elasticity by 73% for the 60% HDPE sample. Finally, one can say that using HDPE waste in mortar composites enhanced the building performance thermally and acoustically. Besides, it is a more flexible material with higher shock resistance [21].

5.3. Reinforced Mortar with Plastic Fibers

Beddu et al. studied the thermomechanical properties of cement mortar reinforced with polypropylene fibers (PP) as reinforcement to increase the tensile strength. The study prepared mortar type M, which is a heavy type that uses the highest amount of Portland cement compared to other mortar types. As mentioned in previous studies, a higher thermal conductivity is obtained with the increase of the PW amount. Cement mortar was prepared in a cement/sand ratio of 1:3 mix according to ASTM C91 standards. The best water/cement ratio was 0.5 % based on many tests provided with 2% superplasticizer, which is a water-soluble solution with the purpose of reducing water demand while mixing. This will enhance the mechanical properties of the composite, like strength, thermal shrinkage and cracking. Polypropylene (PP) fibers were added with a length of 19mm and a percentage of 0.15%, 0.2% and 0.3%. A reduction of 10% in compressive strength is detected, as shown in Figure (11), by adding 0.1% PP, 13% by adding 0.2 % and 29% by adding 0.3 %PP in regard to the control specimen. With 0.1 % PP the tensile strength increased by 50%. While the 0.3% PP mortar mix has the highest tensile strength (7.32 MPa), it has the lowest compressive strength. These results show the potentials of using PP fibers in cement mortar to increase tensile strength and decrease micro cracking. Comparing the value of the thermal conductivity with the reference sample, it was decreased to 8%, 12% and 14% for the 0.1%, 0.2% and 0.3% PP mortar mix, respectively. A heat transfer lag occurs, due to air gaps that are created between the components [22].

6. Results and Discussion

All analyzed studies assert that plastic waste content is the most effective parameter on the thermomechanical properties of the developed composites, followed by the size of the plastic particle. Changing the type of the used plastic is less effective on the compressive strength and barely affects the thermal conductivity. They all agreed upon the adverse effect of increasing plastic waste content on the compressive strength, thermal conductivity, unit weight and bulk density of brick, concrete or mortar. Regarding the compressive strength, all previous results reflect the same trend of the descending curves, but with different degrees of inclination from slight to gradual to sharp, as shown in figure (12). The higher the plastic content, the lower gets the compressive strength as a result of reducing the adhesive strength between the components of the composites and plastic which creates porous structure. The reduction of the compressive strength falls gradually with a limited increase of plastic then degrades sharply with higher content. Other factors that significantly influence the composites' properties are the types and ratios of the components, the quality and grade of cement, w/c ratio and particle size. Smaller particle size minimizes the degradation of compressive strength because less pores are created [15,17]. The lower the w/c ratio, the higher is the compressive strength [19].The findings also show the proportionality between the bulk density and the compressive strength of the composites containing plastic waste, as shown in Figure (13). Also both properties reflect the same declining behaviour with the increase of plastic waste amount, as illustrated in Figure (12) and (14). The reason for the bulk density reduction relies in the lower density of plastic (0.9- 1.3 g/cm^3) compared to that of aggregates (1.6g/cm^3 and 2g/cm^3). In other words, the weight of the plastic volume needed to fill the replaced volume of natural aggregate is lower than that of the aggregate. The following equations relate bulk density to weight and volume:

$$\text{Bulk Density} = \text{Weight of aggregate/Container of unit volume} \quad [23]$$

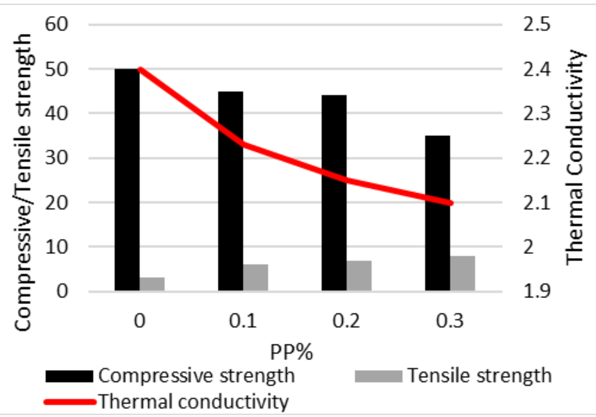

Figure 11. Compressive Strength, tensile strength & thermal conductivity of Mortar with PP

Regarding thermal conductivity, all studies have the same trend of regression with the increase of plastic waste content, as presented in Figure (15). The results are slightly affected by the change of plastic type [15,16,21], but are more affected by the size of the particles. The larger the grain size the lower is the thermal conductivity, due to the greater amounts of created air cavities. Besides, a good correlation was found between thermal conductivity and bulk density, and they are directly related to the bulk density, as shown in Figure (16). Composites with higher plastic content experienced lower thermal conductivity as well as bulk density.

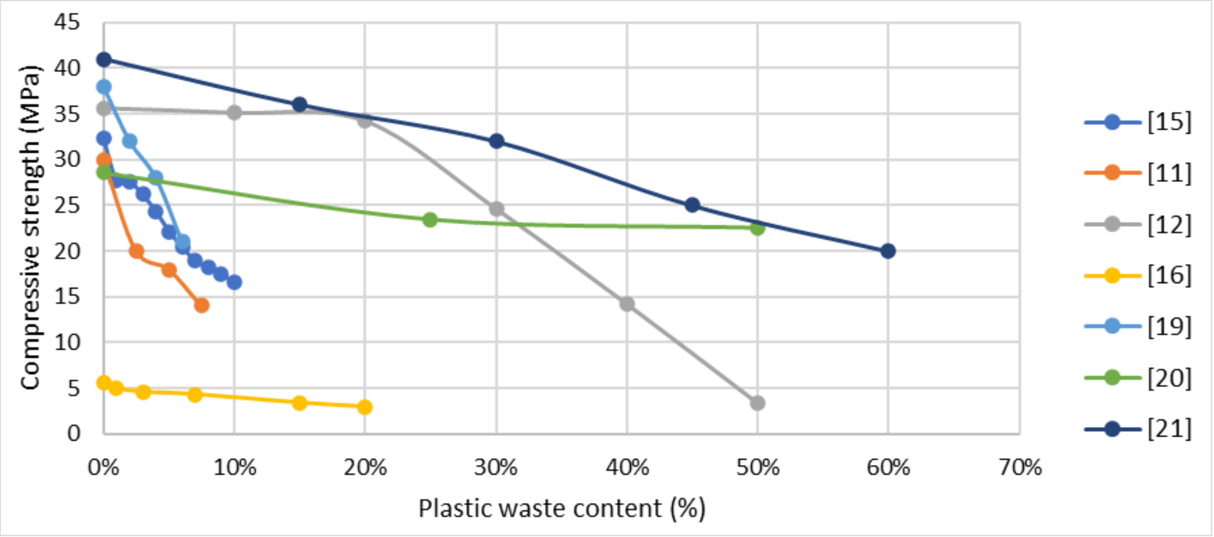

Figure 12. Compressive strength & plastic waste content of previous studies

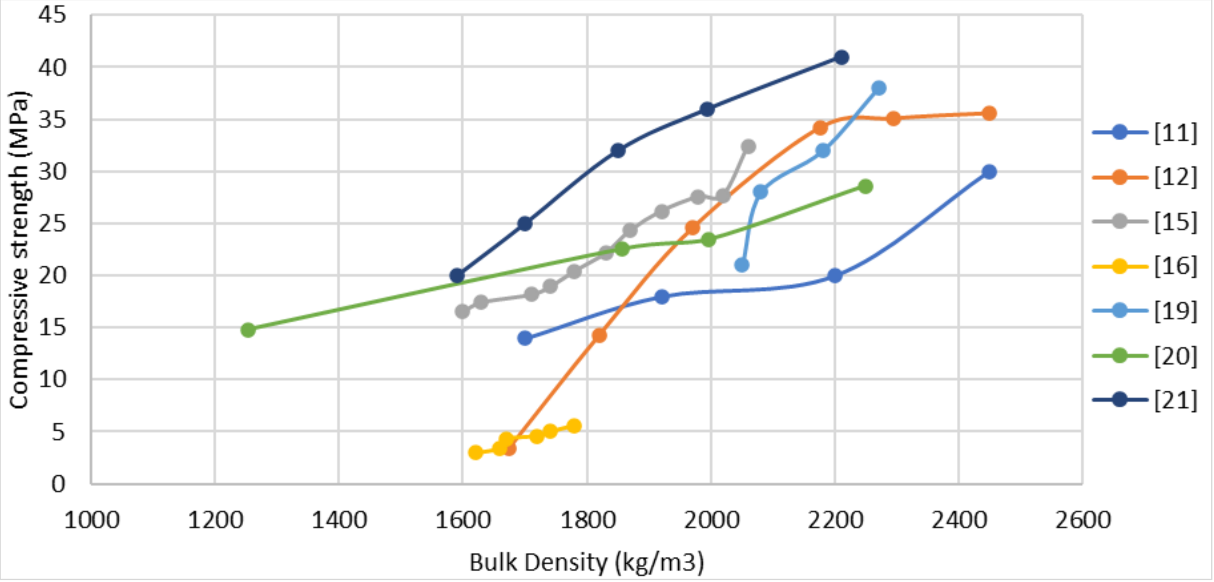

Figure 13. Compressive strength & bulk density of previous studies

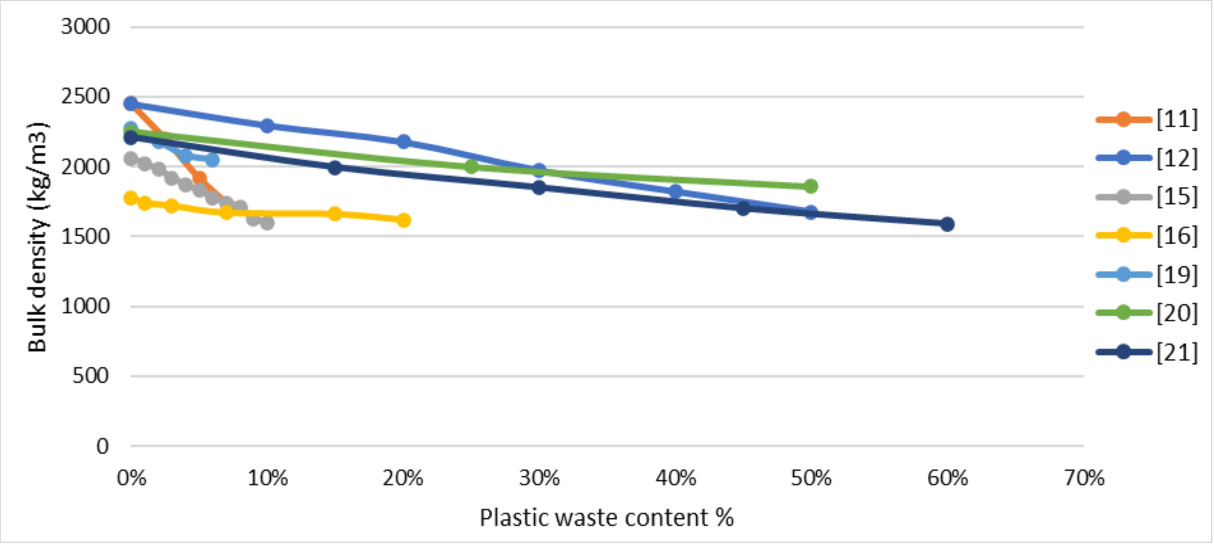

Figure 14. Bulk density &plastic waste content of previous studies

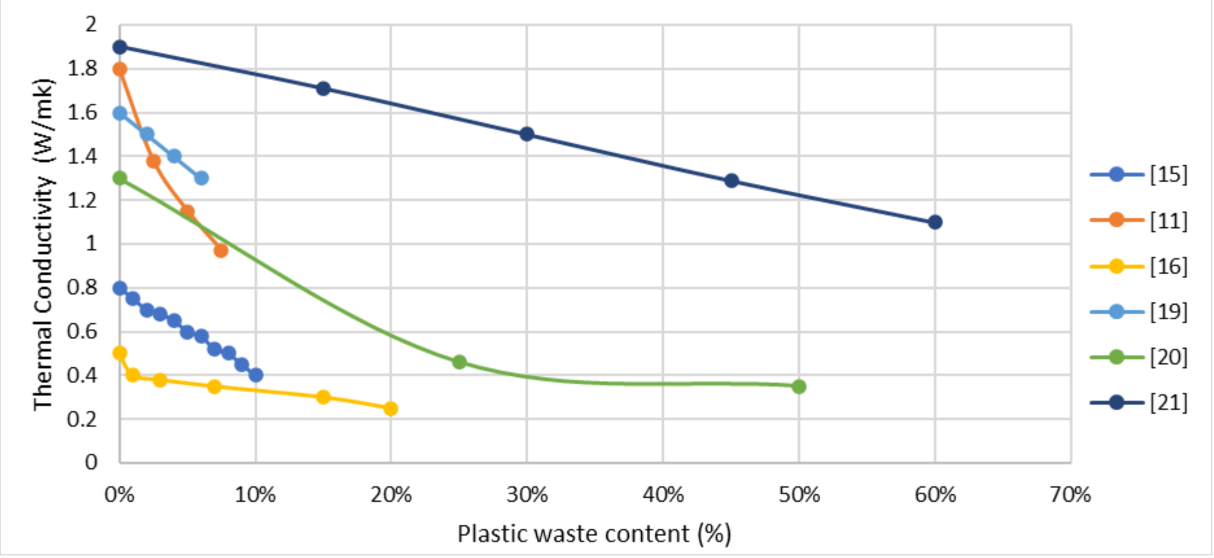

Figure 15. Thermal conductivity & plastic waste content of previous studies

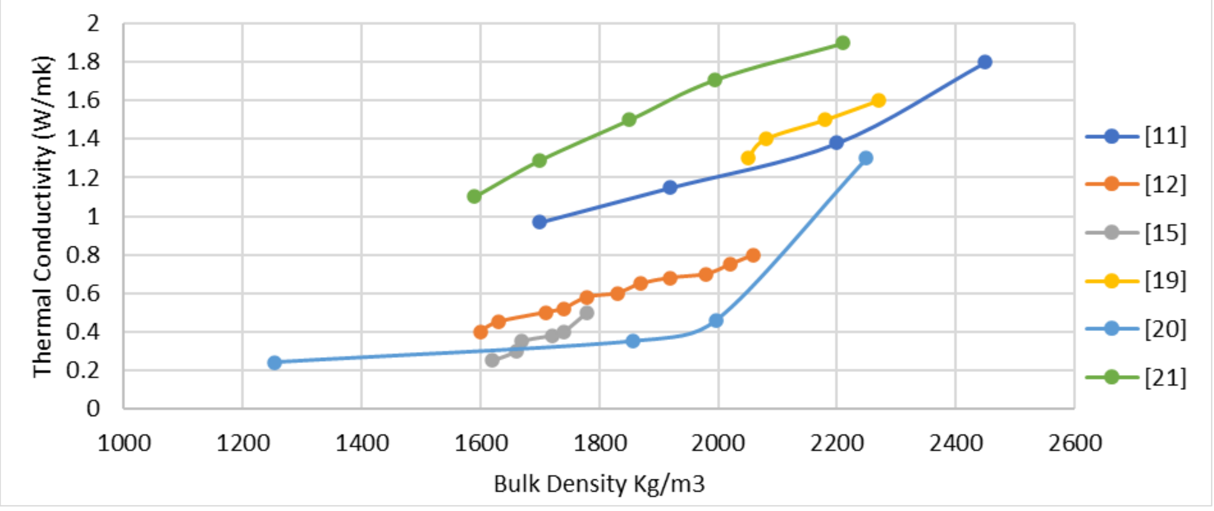

Figure 16. Thermal conductivity & bulk density of previous studies

Table (1) sets guidelines for using plastic waste in different construction applications, in terms of plastic type, content and size. In previous studies, the optimum content varies among the studies based on the purpose of application. For load bearing structures, specifically in concrete, researchers recommended applying plastic waste in a limited amount, up to 5%. The compression strength decreased more by replacing cement with plastic. For non-load bearing brick walls, the optimum content is about 10%. Higher plastic content can be used in lightweight structures or low-rise buildings. In mortar that is used for plastering purposes and does not require high strength, up to 60% of sand can be replaced with plastic. However, adhesion properties should be further investigated. Benefits of using plastic waste on the environment are significant; it reduces plastic pollution, minimizes the use of raw materials, saves energy consumption by employing plastic waste as thermal insulator which enhances the building thermal performance. Besides, producing lightweight material decreases the transportation cost of the material and the deadload of the building. In addition, cost efficient materials can be developed by substituting aggregates with plastic, due to the low cost of plastic.

Table 1. Guidelines for using plastic waste in different applications

Plastic Waste Type	Waste Size, Percentage	Application	Compressive Strength	Thermal Conductivity	Optimum % of PW	References
PET (shredded)	2.5%, 5%, 7.5%	Partial Replacement of Coarse Aggregates in Concrete	20, 18, 14	H 1.38, L 0.7	5% PET CS 18MPa K 1.15	[11]
PET (granulated)	10%, 20%, 30%, 40%, 50%	Partial Replacement of Sand in Concrete	H 35 L 14.4	N.A	30% CS 24.7	[12]
HDPE & PET	1%, 3%, 7%, 15% and 20%) $\delta \leq 1$ mm 1 mm $< \delta \leq 3$ mm 3 mm $< \delta \leq 6$ mm)	Additives to Unfired Clay Brick	H 5.04 L 2.2	H 0.46 L 0.2	HDPE 7% CS 4.43 K 0.33	[14]
Polycarbonate, Polystyrene, Mixed Plastic	1% -10%	Partial Replacement of Sand in Cement Fly Ash Bricks	H 32 L 17	H 0.8 L 0.4	Polycarbonate 10% CS 17.34 K 0.4	[15]
LDPE	50-100% LDPE Different Sand size 0.5mm-3.5mm	Binder in Sand-LDPE Bonded Brick	H 27.4 L 13	N.A	75% Sand size 0.5mm +25% LDPE CS 27.4	[17]
HDPE	15%, 30%, 45%, 60%	Partial Replacement of Sand in Mortar	H 39 L 18	H 2.1 L 1	60% CS 25 K 1	[21]
Polypropylene fibres	0.1, 0.2, 0.3	Reinforcement in Mortar	H 38 L35		0.3% CS 35 K 2	[22]
PVC	25%, 50%,100	Partial Replacement	H 23.5 L 14.8	H 0.46 L 0.24	25% PVC CS 23.5 K 0.46	[20]
HDPE	2%, 4%, 6%	Partial Replacement of Cement in Mortar	H 45 L 21	H 1.6 L 1.4	6% CS 21 K 1.4	[19]

7. Conclusions

This review employs experimental studies of previous research that investigated thermomechanical properties of plastic waste composites. Findings have proven that plastic waste has great potential to be used as an alternative construction material. The compressive strength is affected by the type, size and the percentage of the polymeric additives that are used. The larger the grain size, the higher the compressive strength and the lower the thermal conductivity. In all studies the compressive strength, density as well as the thermal conductivity decreased regardless the type of plastics used. The amount of the plastic content has significant impact on these properties. It has been recommended to implement plastic waste to certain limits, up to 5% for the loadbearing structures. This amount maybe increased for non-load bearing walls and mortars. Providing mortar composite with plastic fibers may improve the thermomechanical properties, as increasing tensile strength, decreasing micro cracking and increasing thermal insulation. [24]

In addition, replacing natural aggregates as sand with plastic waste decreases the unit weight of concrete, due to the lightweight of PW. Lightweight material has great benefits in construction; it reduces transportation, thermal insulation, cost and manufacturing time. Another important fact, the low thermal conductivity of plastic waste reduces the thermal conductivity of the building materials. Enhancing the building energy performance minimizes the energy consumption used for the cooling and heating. Implementing plastic waste in building materials is an environmentally friendly way of disposal and has shown suitable properties.

8. Recommendation and Further Research

Further research is recommended to set standards for these types of construction materials in order to implement them in the building codes. The commercial production of building materials with plastic waste is still very limited, hence a development of these applications is required to release it in the market and to encourage mass production. Besides, a cost analysis is needed to calculate the savings that can result from substituting conventional construction materials with plastic waste.

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