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UTILIZING WASTE PLASTIC POLYPROPYLENE AND POLYETHYLENE TEREPHTHALATE AS ALTERNATIVE AGGREGATES TO PRODUCE LIGHTWEIGHT CONCRETE: A REVIEW

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Abstract

In recent times, there is an increasing need for the fabrication of mortar and concrete that can be characterised as sustainable and environmentally friendly. Ideally, this concrete should be inexpensive, lightweight, and outstanding in terms of its physical and mechanical specifications. Plastic materials have increasingly been used in the fabrication of different types of concrete admixtures and mortar constituents. These plastic materials take the form of fillers or shredded fibres derived from polypropylene and polyethylene terephthalate. The use of plastic materials presents the following benefits: (i) enhanced mixture quality and (ii) a reduction in the amount of accumulated single-use plastic materials that negatively impact the environment. This work reviews several previous studies on the utilisation and preparations of plastic materials and their effects on the physical and mechanical properties of concrete. Other topics, including hardened concrete, fresh concrete, application, and thermo-physical characteristics, are also elaborated.

Keywords: Concrete, Fresh concrete, Flexure strength, Compressive strength, Insulation.

1. Introduction

Plastic is the most significant industrial metal in our life of the last century and today, it is available almost everywhere. Replacing or compensating for plastic and other material is a practice that has become widespread of late, given the increasing trend of plastic waste build-up. The existence of such waste results in a negative environmental impact. It hinders the drainage of water through the soil, which then pollutes the soil with diseases triggered by mosquitoes and diseases resulting from the flood water flow. The presence of plastic blocks seepage pipes in urban areas. Furthermore, such plastic blockages hinder or prolong the movement of plant roots. The blocks include certain toxic substances in their chemical compositions, thus exposing the future of the soil to risk factors that arise after decomposition occurs [1].

There are many forms of waste plastic utilized to produce light weight concrete, polyethylene terephthalate (PET) slices shredded by the machine used [2-9]. Several studies were also conducted using handheld devices to cut plastic [10, 11], while Irwan et al. [12] used a grinding machine which produced fibre in irregular forms. Some researchers used the PET as a single additive material in concrete [2, 6, 8-11], while [3, 7] used polypropylene (PP) material to be compared with the PET result.

The aim of this review paper is to summarise the previous studies on waste plastic materials such as PET and PP over the past two decades to draw generalised conclusions regarding the investigations of fresh/hardened concrete characteristics and mix designs and applications. The paper will also highlight areas of progress in this field that require further investigation, and provide outline suggestions for future investigations and research priorities.

2. Preparation of Material

In previous studies on the waste that accumulates as a result of the use of plastic materials, a number of processes and configurations have been proposed to minimise the impact of these materials on the environment. These processes include plastic washing before the chipping or grinding process. Other studies focused on determining the appropriate amount of material to be used in concrete admixtures and the treatments that the materials should undergo. These subjects are only some of the topics covered in previous studies. In this paper, a detailed review of earlier findings, amount of plastic material and treatments proposed in previous works will be discussed.

2.1. Preparation of waste plastic

The huge volume of plastic utilised to enhance the properties of concrete is secured from the waste treatment sites, which include plastic material gathered from different sources. In previous researches, a few techniques such as chipping machines or manual cutting were used to obtain the shape of the plastic material or body involved in the creation of the concrete mix. Different types of crusher like propeller crushers or blade mills are used to grind the plastic waste [1]. One such technique is shredding plastic bottles by deploying specially designed machines into small, skinny tapes [2-9]. The slide length falls in the range of 7-50 mm.

Previous studies [5, 9] also have indicated that shredding operations occasionally include more than one step to produce more than one type of plastic, such as PET and PP. Some studies require the plastic materials to undergo a washing process to remove loose materials and thus avoid their side effects on the concrete mix process [2, 3, 10]. By shredding polypropylene to improve the mechanical properties of concrete, Muttar [13] used 19 mm PET slices, which were washed clean by water before use, to prepare the mixes. Some studies were also conducted using handheld devices to cut plastic [10, 11]. Here, the chips' lengths ranged between 15 mm and 50 mm. The process of grinding the plastic materials plays a significant role in the beginning by improving the mechanical properties of concrete. This is when the plastic bottles were undergoing grinding in the laboratory with the use of special grinding machines; they were sieved to obtain suitable particle sizes for each mixture. From recycled bottle wastes, straight PET fibre underwent grinding in a granulator machine, which produced fibre in irregular forms [12].

2.2. Types and amounts of substitution of natural aggregate by waste plastic

Generally, large-sized plastic waste materials produce plastic fibres as slices and aggregate. Thus, coarse and fine-sized natural aggregate can both be used to prepare the mixes, replacing shredded plastic. Several studies reported both partial and full substitutions of natural aggregates with shredded plastic. In some of these studies, coarse-sized aggregates, fine aggregates or cement were also replaced by shredded plastic [14-17]. The types and amounts of shredded plastic used to substitute natural aggregate in preparing cement concrete are shown in Table 1.

Table 1. Types of substitution of natural aggregate by shredded plastic fibre in cement and concrete.

References	Origin of waste plastic	Type of composite	Amount and type of substitution
[2]	PET-bottle	concrete	0,0 .5% of cement
[11]	PET	concrete	0, 0.5, 1.5, 2.3, 3.0% of sand
[10]	PET	concrete	0.5, 1.0, 1.5% of cement
[14]	PET	Lightweight concrete	50% of sand
[3]	PET,PP	concrete	1% of vol* of mix
[4]	Mixture of Nylon and PP	concrete	0.6kg/m^3
[5]	PP	Lightweight concrete	0, 0.28, 0.56, 1% vol. of mix.
[6]	PET-bags	concrete	0.3, 0.6, 0.9, 1.2% vol. of mix
[7]	PET,PP	concrete	0.5, 0.75, 1% vol. of mix
[8]	PET	concrete	13.4 kg/m^3
[9]	PET	Mortar	0, 0.5, 1.0, 1.5% vol. of mix

*vol.= total volume of mix

2.3. Preparation and curing of specimens containing waste plastic

The process of preparing and casting the concrete mix containing shredded plastic is generally similar to the normal concrete preparations steps. It is also performed according to several standard specifications. In some cases, however, slightly different approaches were used to design and cure some of the concrete mixes that contained shredded plastic. In one case, the specimens were de-moulded only after 24 h in the laboratory. All specimens were then kept under nylon sheets inside the laboratory for an additional 24 h. Later, they were de-moulded and, until the time of the test, they remained submerged in the water basin [18]. The tests were applied to the specimens for various lengths of time, such as 3, 7, 14, 28, and 56 days.

3. Fresh Concrete Properties

To test the workability of the concrete, it is important to conduct tests before its use (fresh concrete) or after casting (hardened concrete). The unit weight/density and slump test serve to be the most important tests.

3.1. Unit weight/dry density/fresh concrete

Density is the measured weight of the amount of concrete occupying one cubic meter of vacuum because concrete is a mixture of several key components (i.e., cement, sand, gravel and water). Individual components such as sand, gravel or cement may be partially or totally replaced by fly ash, slag or plastic materials to reduce costs or produce lightweight concrete. The shredded plastic has light weight and high strength properties that can change the normal concrete to lightweight concrete. Normally, the mass density of the concrete stands at 2400 kg/m^3, whereas the mass density of lightweight concrete contains shredded plastic can decrease to 1750 kg/m^3 [19]. Previous studies (see Table 2) on concrete and mortar mixes showed the ratio on plastic substitution and influence on the unit weight and density.

As observed in Table 2, researchers [15, 17, 20-22] have discovered that adding the plastic material to the mixes of concrete or mortar will reduced the unit weight and density, where the replacement of 5% to 60% of the natural sand by plastic caused a reduction of approximately 0.6% to 46%.

In contrast, using 0.1% and 0.2% of the volume of the mixes caused an increase in the unit weight and density of approximately 2.5% to 7% [14, 18].When the proportion of the total volume of the mixture was replaced by a ratio of plastic material, it produced two effects. Replacing 0.5% and 1.5% of the volume of the mixture resulted in a reduction in the unit weight and density of approximately 4% to 12% [23].However, a number of researchers concluded that adding plastic material to the concrete or mortar mixes had no clear effect on the unit weight and density [9, 24].

3.2. Slump

Slump is a method to determine the degree of wet concrete, considering that there are several types of concrete consistency (e.g., plastic concrete, wet concrete, hard concrete, dry concrete and sloppy concrete). Slump refers to the relationship between the amount of water and the dry materials used in the concrete mix. The purpose of such a test is to ensure that the specification of the concrete mix adheres to the structural purpose for which it was made. The factors that affected the results of the examination represent the ratio of the main components involved in forming the mixture (i.e., water, cement, sand and gravel). Also exerting significant effects on the shape of the collapse are the smoothness of the cement, the time elapsed between the processing of the batches, the conduct of the test, and the temperature mixing site. The majority of the past studies emphasized the slump test that marked the start of the experimental research. Table 3 highlights the relationship between slump and the presence of plastic in concrete and mortar mixes.

Table 3 indicates the work of many researchers who proved that adding plastic material to concrete mixtures or mortars contributed in reducing losses in the concrete slump test. Song et al. [4] maintained that the addition of plastic at 0.6 kg/m^3 to the mix caused a reduction of approximately 25% in the slump losses. However, another study by Kayali et al. [5] proved that adding plastic to mixes at 0.56% of the total mix volume did not have any clear effect on the slump test.

The presence of plastic in the mixes in proportions ranging from 0.5% to 2.3% of the total volume of the mixes also contributed to the reduction of losses to 70% [11, 23]. The added plastic material increased the cohesion of the mixture components with keeping the workability of concrete at acceptable status, and it did not collapse when the slump test's conical cylinder was lifted, staying upright in a conical shape [4, 11, 15, 22-26].When the added rates ranged between 10% and 60%, the presence of plastic materials in mixtures of sand volume may reduce the losses by 7% to 95.3% [15, 22, 24, 25].

Table 2. Plastic ratio and the influence on unit weight and dry density of concrete.

References	Plastic ratio substitution	Influence on the concrete density	Influence percentage
[23]	0.5% and 1.5% of vol	Reduce	4% and 12%
[15]	10%,15% and 20% of sand	Reduce	5%,6.25% and9%
[17]	5%,10% and 15% of sand	Reduce	1% to 3%
[20]	10%,30% and 50% of sand	Reduce	2.5%, 0.6% and 13%
[21]	5%,10% and 15% of sand	Reduce	2.5%, 5% and 7%
[22]	30%,40%,50% and 60% of sand	Reduce	15%, 26%,30% and 46%
[14]	PET and PET+sand	Increase	2.5% and 3.5%
[18]	0.1% and0.2% of vol	Increase	5% and 7%
[9]	0.5%,1% and 1.5% of sand	No effect	0%
[24]	5%,10%,15% and 20% of sand	No effect	0%

Table 3. Plastic presence and influence it on the slump behaviour in mixes.

References	Plastic ratio substitution	Influence on the slump	Influence percentage
[23]	0.5%,1.0% and 1.5% of vol	Reduce slump	16%, 29% and 65%
[4]	0.6kg/m^3	Reduce slump	25%
[11]	0.5%,1%,1.5% and 2.3% of vol	Reduce slump	70%, 58%,0% and 0%
[15]	10%,15% and 20% of sand	Reduce slump	68.3%,88.3% and 95.3%
[22]	30%,40%,50% and 60% of sand	Reduce slump	7% to 20%
[24]	20% of sand	Reduce slump	25%
[25]	10%,15%,20% and 30% of sand	Reduce slump	40%, 44%,46% and 50%
[5]	0.56% of vol	No effect	0%

4. Hardened Concrete Properties

In order to investigate the effect of plastic in the concrete mixes, several hardened concrete tests need to be carried out such as compressive strength, tensile strength (splitting strength), flexural strength (bending strength), impact resistant strength, ultrasonic test and scanning electron microscopy (SEM) activity.

4.1. Compressive strength

Compressive strength represents the ability of the material to resist pressure applied by the compression machine, where the sample shattering when it passes the limits of compressive strength. Some of the concrete mixes possess a compressive strength of more than 50 MPa. In a certain experiment, when a sample of the material is subjected to a load that leads to a failure, the condition is called a pressurised situation. Here, the pressures bring closer the constituent particle materials for concrete work against each other [26]. Fraternali et al. [3] proved that substituting plastic materials for 1% of the total mix volume could improve the compressive strength by as much as 35%. PET can be utilised for resin manufacturing; in the same fashion, unsaturated polyester can be applied in a glycol-impregnated environment, whereas dibasic acid applicable to an environment that stimulates the manufacturing of mechanicals characterised by top enforcement is produced by concrete binder polymer [27-31]. Table 4 summarizes the finding from previous researches on the impact of plastic on the compressive strength of mixes.

Using of plastic materials in concrete mixes enhanced the compressive strength by approximately 8% to 14.2% for substitution ratios at a value between 0.1% to 0.5% of the mix volume [12, 18, 23]. Adding plastic material in amounts ranging from 1 kg/m^3 to 1.5 kg/m^3 could improve the compressive strength anywhere from 32% to 34% [32].

Other researchers opted to use a greater volume of plastic materials at a range of 0.6% to 1.5% of the total mix volumes, and the results showed reductions in the compressive strength from 4% to as high as 43% [6, 11, 12, 23]. In contrast, Jo et al. [16] found that compressive strength did not exhibit any significant changes when plastic materials were added. Substituting plastic materials for natural sand at a volume from 20% to 60% could significantly deteriorate the compressive strength by 71% to 78% [22, 24].

Table 4. Relation between plastic ratio and its influence on compressive strength in mixes.

References	Plastic ratio substitution	Influence on the strength	Influence percentage
[23]	0.5% of vol	Increase	11.6%
[3]	1% of vol	Increase	35%
[12]	0.5% of vol 1% and 1.5 of vol	Increase Decrease	8% 4% and 8%
[18]	0.1% and 0.2% of vol	Increase	11.42% and 14.28%
[32]	1kg and 1.5kg/m^3	Increase	32% and 34%
[6]	0.6% and 1.2% of vol	Decrease	32% and 43%
[11]	0.5% of vol	Decrease	30%
[22]	30%,40%,50% and 60% of sand	Decrease	41%,54%,62% and 78%
[24]	20% of sand	Decrease	71%
[16]	Resin of PET (liquid)	No effect	0%

4.2. Tensile strength (splitting strength)

Normally, hardened concrete is known capable to withstanding a large amount of both directly and indirectly applied pressure. Thus, one objective is to enhance the tensile strength of concrete mixtures because concrete is, in fact, a brittle material. The splitting tensile strength of nylon-fiber-reinforced concrete tended to improve most, the tendency repeated itself for the polypropylene fiber concrete [4]. Researchers have focused on developing this characteristic of concrete because the occurrence of cracks directly results from low tensile strength. In Table 5, the effects of different amounts of plastic materials on tensile strength are outlined.

In fact, 0.6 kg/m^3 of plastic material could improve the tensile strength by up to 9.7% [4]. The integration of plastic materials at a volume of 0.5% to 1.5% into concrete admixtures or mortars could account for a significant increase in tensile strength that reached 23.6% [2, 12]. A number of scholars found that substituting plastic material for 15% to 20% of the natural sand volume in a concrete mix would decrease the tensile strength by 18% to 50% [17, 24].

Table 5. Influence of ratios of plastic on tensile strength of mixes.

References	Plastic ratio substitution	Influence on the mixes	Influence percentage
[2]	0.5% of vol	Increase	1.63%
[12]	0.5%,1.0% and 1.5% of vol	Increase	9.1%,15.5%,23.6%
[4]	0.6kg/m^3	Increase	9.7%
[17]	15% of sand	Decrease	18.06%
[24]	20% of sand	Decrease	50%

4.3. Flexural strength (bending strength)

Flexural strength can be described as a concrete beam's ability to withstand applied loads without failure. In most previous studies, samples with dimensions of 100 × 100 × 500 mm were typically used, with the length designated to be four to five times the depth of the section as used by [5,17]

The relationship between plastic ratio and flexural strength is demonstrated in Table 6. The adding an amount of plastic equal to 0.56% of the total volume could enhance the flexural strength by up to 20% [5].One study revealed that adding plastic by 0.5% of the total volume of concrete could decrease the flexural strength by 41% [23].

Meanwhile, Silva et al. [32] found that an amount of plastic equal to 0.4% to 0.8% of the volume exhibited no distinctive influence on the flexural strength. Substituting sand with plastic ratios of 15% to 50% of the total volume resulted in a 6.25% to 18% decrease in the flexural strength [17, 33]. Conversely, Hannawi et al. [33] found no effect of a 10% substitution of sand volume on the flexural strength.

Table 6. Influence of plastic on the flexure strength of concrete.

References	Plastic ratio substitution	Influence on the flexure strength	Influence percentage
[23]	0.5% of vol	Decrease	41%
[17]	15% of sand	Decrease	6.25%
	5% of sand	Increase	8.02%
[5]	0.56% of vol	Increase	20%
[33]	20% and 50% of sand	Decrease	9.5% and 17.9%
	10% of sand	No effect	0%
[32]	0.4% and 0.8% of vol	No effect	0%

4.4. Impact resistance

Many researchers have found that the addition of plastic material contributes to the enhancement of concrete resistance. Song et al. [4] examined the influence of nylon versus polypropylene on the hardened properties of concrete. The disc form was used for impact specimens, each of which measured 15 × 6.4 cm. A drop weight test was conducted, and the findings were statistically assessed. The mean first-crack and failure strengths of nylon-fibre-reinforced discs increased by 19.0% and 30.5% compared with the plain control discs, whereas the values for the polypropylene-fibre-reinforced discs were 11.9% and 17.0%, respectively.

Al-Hadithi A.I. [10] focused on the impact resistance of concrete slabs with varying volume percentage replacement ratios of waste plastic fibres (PET). Their findings revealed a significant improvement in the low-velocity impact resistance of all concrete mixes that had been integrated with waste plastics compared with the reference mix. The enhancement of waste fibre percentage results in a larger number of blows being required to initiate both the first crack and failure compared to the reference mix. The significance of the increase varied from (126%) at (0.5%) ratio to (340%) for (1.5%) ratio of the mix volume upon failure.

The addition of plastic material to the concrete mix was also proven to enhance ductility [34].

4.5. Ultrasonic test

The addition of plastic materials to the concrete mix accounts for the porosity and running dispersal of the transmitted ultrasonic speed [17]. The ultrasonic transmission speed value also increased when the density of concrete was light, thus causing a reduction in the transmission of ultrasonic speed [22].To measure the ultrasonic velocity of a transducer at a vibration frequency of 52 kHz, an ultrasonic non-destructive electronic machine (PUNDIT MODEL PC1012) with an accuracy of 0.1 μs was used. An accuracy of ±1% for travel time and ±2% for distance was also employed. A total of nine measurements were taken for three cubic samples of each design, which had dimensions of 10 cm^3 and various ages. The minimum time among the samples was then recorded. Vaseline was used to merge the transducer's surface to the concrete sample surface during the test [35].

Albano et al. [36] argued that the ultrasonic speed influences the coarseness and softness of the additive. Plastic material at an amount of 5% to 20% of the volume of sand was added to the concrete mix, which caused a decrease in the transmission speed of the ultrasonic machine [17, 22, 36, 37]. A linear relationship was observed between the speed of transmission of the ultrasonic device and the compressive strength, which reached a final value greater than the speed of the transmission.

4.6. Scanning electron microscopy (SEM) activity in previous studies

A number of previous studies of concrete employed the scanning electron microscopy (SEM) in testing samples to determine the sample components and compare various samples in different fields of materials science. The use of the SEM revealed a weak bonding between the mixture components that contained plastic materials. Such weak bonding resulted in decreased compressive strength between basic mix materials and shredded plastic [22]. Microscopic images of a specimen containing PP fibres were observed to scrutinise the effects of these fibres on the cracking and strength of concrete. The fibres were found within the formed crack and they served as connecting bridges that prevented the separation of concrete pieces after cracking. A previous study presented a schematic representation of how fibres can form a connecting bridge to prevent crack propagation [32].

SEM approved high activity through testing the concrete specimens where gave clear idea about the entire structure of concrete [38]. The findings on the occurrence of bonding between PET and grains of sand were proven to be positive with the use of the SEM, and the results revealed a regular distribution of the PET within the specimens [39].

5. Behavior of Plastic Waste Concrete Upon Fire Exposure

Some of the mechanical characteristics of concrete are lost upon the subjection to high temperatures, especially temperatures above 300°C. Concrete behaviour is tested at high temperatures to evaluate its resistance to fire and place this resistance on the temperature curve of allowed heat exposure. When subjected to temperatures of 400°C or higher, the calcium hydroxide present in the cement will start evaporating and will cause its strength to decrease considerably, thereby altering the overall qualities of the material, as emphasised in [40].

According to Han et al. [41], if a 0.05% ratio of (PP) waste plastic materials is added to the concrete, provided that it is evaluated in the same high-temperature conditions, the resilience of the concrete and its coherence with the waste plastic materials will be greatly reduced. The usage of waste plastic materials (PET) along with glycol at the ratio of 2:1 has a positive effect on raising the compressive strength of polymer concrete. Mahdi et al. [42] said the compressive strength of concrete exhibits a reduction when it is exposed to high temperatures. Concrete is negatively affected by temperatures of 60°C and higher, especially where the compressive strength is concerned [43].

6. Thermo-Physical Properties

Many research works [3, 22, 44] agree on the impact of plastic in concrete. More specifically, they are unified on the determination that plastic has a significant effect on the concrete characteristics under the additional influence of high temperatures. If the plastic concentration is upgraded from 30% to 60% sand volume, pressure is placed on the concrete mix due to the decreased heat conductivity. Fraternali et al. [3] confirmed that when concrete is tested at 20°C, or room temperature, mixing it with plastic materials reduces its thermal strength by 18% compared with the reference sample. The conductivity of the PET (plastic-saturated concrete) reduces from 0.6118 w/m.k to 0.3924 w/m.k, the heat resistance falls considerably compared with the reference sample, usually by 34% to 58% [22].

Adding PET more specifically to the concrete mixture increases the heat cushioning of the concrete from 10.27% to 18.16% according to the geometrical dimensions of the material [44]. Dweik et al. [45] proved that the presence of plastic in concrete was shown to affect its insulation increase rate, whereas Mounanga et al. [46] proved that the thermal conductivity of concrete, whose structure is characterized by the presence of plastic bits, was shown to be lower to that of regular concrete .The laboratory tests is the key of the mechanical properties behavior for any type of concrete such as normal concrete or concrete contains addition materials [47].

7. PET and PP-Altered Concrete Applications

The plastic-saturated concrete mixtures are not sufficiently used in constructions projects. However, there is a sufficient amount of information to prove the beneficial effect of such material in operations such as road construction or pavement work due to the skimming of concrete in natural weather conditions [1].

The plastic mixtures can be used as whole structures or as structural elements. The Sumitomo Metal Mining Company, for example, has used shotcrete (lightweight concrete containing PET) to construct one of Japan's central gates; namely, the one in the Hishikari State. Quality analyses of the work on the gate have proven that the addition of PET to the concrete not only ensured effortless spraying of the mine gate but also resulted in perfect quality production in which no flakes or swells were detected, and no additional problems were observed.

PET-altered concrete is also applied in cases where narrow alleyways are required, usually when tunnels or underground structures are receiving work. The material is very suitable because using small plastic fibre crumbs instead of steel chunks in reinforced concrete guarantees the safety of the car tires (as opposed to regular pavement resulting in possible deflations). A specific example of such an application is one of the bridging arteries between Kanazawa and Hayatogawa, which was built in 2004 and totals 20 miles in length, 13 cm in girth, and from 3.6 m to 4.9 m in width [48].

In Li et al. [49], the use of concrete structures with PET and PP elements was confirmed. These concrete mixtures are, in addition to the examples above, suitable for the maintenance of roads, dams, bridges, rods, and other structures with concrete surfaces, which are endangered by collateral damage. The efficiency of the concrete contains plastic make the plastic materials suitable to be utilised in the manufacturing of manholes and pipes for water sewage transfer [50-53].

8. Discussions

This review summarizes 44 previous studies on the use of waste plastic materials (PET) and (PP) as an alternative material in concrete mixes since 1994. The studies were classified based on tests conducted on concrete mechanically, physically and by the exposure to fire. Out of the 44 studies, 38 investigated the mechanical properties of fresh and hardened concrete, 5 studies investigated the physical influence of plastic on the thermal insulation of concrete. While 1 study focused on the non-plastic concrete behavior when exposed to fire at high temperatures.

8.1. Mechanical properties of concrete contain PET and PP

Various studies have been conducted in investigating the mechanical properties of concrete mixtures containing PET and PP. Fourteen studies conducted tests on the fresh concrete, represented by slump and unit weight/density tests, whilst another 24 studies investigated tests on the hardened concrete represented by compressive strength, tensile strength, flexural strength, impact resistance and ultrasonic strength tests.

All of these studies were conducted at normal room temperature. Studies conducted on concrete that contains PET and PP exposed to high temperature did not investigate enough so far as shown in Fig. 1. On the other hand, the studies have shown that the presence of PET and PP in the concrete contributed to the improvement of some concrete properties, such as the fact that lightweight concrete and concrete can be produced, both of which characterized by greater ductility compared to normal concrete.

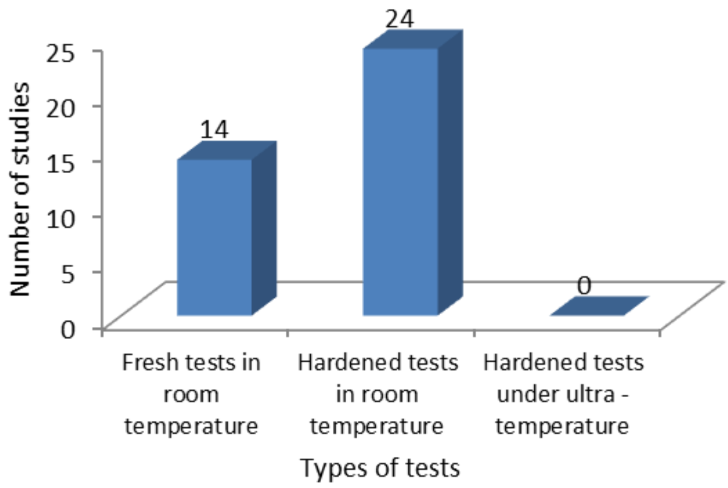

Fig. 1. A number of studies conducted on fresh and hardened tests at room temperature and under ultra-temperature.

This review suggests the use of concrete mixes containing PET and PP in parts of buildings, although the compressive strength in this type of concrete is slightly lower compared with the normal concrete (depends on few studies). This study also suggests using this type of concrete to produce a concrete block masonry that is used to build fences to surround the building, shoulder stone and to produce tiles of paving roads for pedestrians. This is to reduce the economic cost of the products as well as to contribute to the elimination of the negative effect of the presence of plastic in the environment.

8.2. Thermo-physical properties of concrete contain PET and PP

Several studies and briefs have been performed, where they focus on the behavior or role of the PET and PP in concrete. 5 studies have proven that the presence of this plastic material improves the thermal insulation properties of concrete significantly. All the studies were conducted under the influence of natural weather conditions (room temperature), and this means that the Crumb of the plastic remains with the same geometric shape in concrete. Investigating the behavior of concrete containing PET under the influence of high temperatures is scarce and further investigation is needed to see the change that will happen to the body of the plastic crumb form. Figure 2 illustrates the size of the previous studies conducted in this area. This study suggests the use of different sizes of PET Crumbs with Replacement rates with less than a quarter of the amount of sand volume in the composition of the concrete mix.

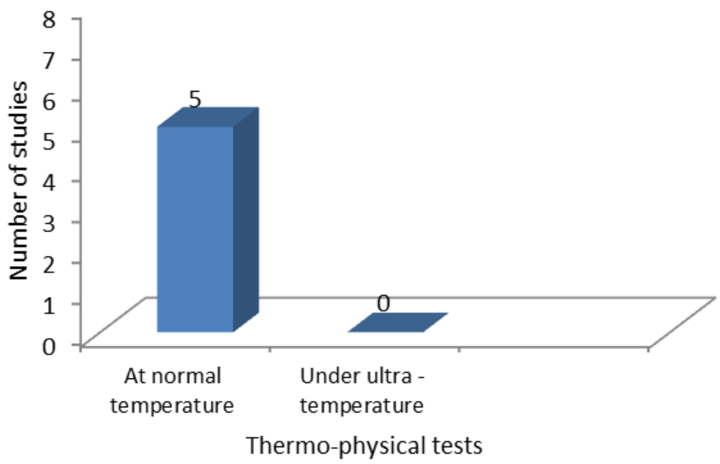

Fig. 2. A number of studies conducted on the influence of PET on the concrete thermal insulation.

8.3. Behavior of concrete under ultra-temperature influence

From the 44 studies summarized in this review study, one study focused on the concrete under the influence of high temperatures, but that type of concrete does not contain PET. The researcher highlighted the effect of the chemical composition of materials involved in the composition of the concrete. This indicates that the behavior of the PET in the concrete exposed to fire was not taken into consideration in the past. This review study suggests an expansion in the investigation of the behavior of the PET in concrete exposed to fire and it also dwells into whether or not it does affect the tensile strength of concrete.

9. Conclusions

Thorough research on PET, PP and other similar plastic materials used in reinforced concrete, concrete mortars and mixtures, instead of natural materials such as sand, have generated results showing that such enhancement is beneficial for the use and application of the concrete. The following conclusions can be drawn from available studies:

- Enhanced to improve concrete slump loss and unit weight density, which results in better quality of workability. This occurs when 0.5% to 1.5% mix volume plastic materials are added to the concrete or, in other words, when mixture rates of up to 50% are applied.
- According to some researchers, if plastic materials at a ratio of 0.1% to 0.5% are added, the blend characteristics and durability can increase up to 14.28%, whereas the compressive strength can be stimulated up to 34% if 1 kg/m^3 is increased to 1.5 kg/m^3. Some other studies, however, indicate some side effects such as decreased compressive strength by up to 40%, depending on the volume of plastic material added. Opinions on the effect of plastic materials on the compressive strength of concrete vary widely between total

uncertainties of such a reaction to decreased compressive power by up to 78%, depending on the ratio of sand use (20–60%).

- It is generally found that plastic materials added to the concrete, mortar or mix strengthen its tensile characteristics by up to 9.7% in quantities up to 0.6 kg/m^3. Meanwhile, the tensile strength can be increased at the range rates from 1.63% to 23.6% by adding the plastic up to 0.5% to 1.5% of the mix volume. On some occasions, however, tensile characteristics may deteriorate by up to 18.06% and 50% after 15% to 20% of sand is substituted with plastic, respectively.
- Opinions on the effect of plastic on flexure strength vary as well. According to some researchers, flexural strength can be expanded up to 20% by the addition of plastic of 0.56% of the total volume. Others argue that the same amount of plastic can reduce the flexural strength up to 41%, while others claim that any addition of 0.4% to 0.8% can generate different results from a huge to non-existent impact on the concrete features. Some research results show that substituting 5% sand with plastic may cause the deterioration of flexural strength up to 8%, whereas 15–50% substitution causes up to 18% decrease in the same characteristics.
- Although many studies and experiments have been conducted with the purpose of establishing the effect of plastic materials on concrete flexibility, only a few have managed to reach specific results. One such study demonstrates that the ductility can be increased up to 3 times compared to the reference sample.
- Researchers have also tested the ultrasound speed transmission in concrete when the concrete mixture is enhanced by plastic materials. They have concluded that such enhancement reduces the ultrasound transmission.
- Researchers using the SEM (scanning electron microscopy) test methodology agree that blending plastic and concrete materials result in perfect material overlay and no discrepancy between the plastic chops and the cement.
- Finally, it is scientifically proven that 60% substitution of sand with plastic results in up to 58% heat conductivity, whereas the subsequent addition of even 1% plastic changes the characteristics of the mixture by decreasing its heat conductivity to 18%.

10. Recommendations for Further Research

Through a review of previous studies, it is required to include recommendations in investigating the impact of waste plastic on the performance of normal concrete as following:

- Plastic is found to be salt-resistant and negatively impacted by the degeneration of the environment. Therefore, sustainable manufacturing of concrete is a great area of interest, and the topic is widely researched by scientists.
- Further research is required to establish the concrete's characteristics and load behavior as impacted by plastic's ductility.

- Waste plastic materials (PET) and their aggregate states have a strong influence on the structure of concrete as well as its competitive performance or lack thereof.
- There is a need to study the effect of PET-aggregate on the creep and shrinkage of high-performance concrete.

Further studies are needed on the use of fibre plastic in addition to concrete types, such as compacted or self-compacted roller concrete, which will present new possibilities to the world of construction, road work and any other areas that require the application of asphalt.

References

1. Saikia, N.; and de Brito, J. (2012). Use of plastic waste as aggregate in cement mortar and concrete preparation: A review. *Construction and Building Materials*, 34, 385-401.
2. Kandasamy, R.; and Murugesan, R. (2011). Fibre reinforced concrete using domestic waste plastics as fibres. *ARPN Journal of Engineering and Applied Sciences*, 6(3), 75-82.
3. Fraternali, F.; Ciancia, V.; Chechile, R.; Rizzano, G.; Feo, L.; and Incarnato, L. (2011). Experimental study of the thermo-mechanical properties of recycled PET fiber-reinforced concrete. *Composite Structures*, 93(9), 2368-2374.
4. Song, P.S.; Hwang, S.; and Sheu, B.C. (2005). Strength properties of nylon- and polypropylene-fiber-reinforced concretes. *Cement and Concrete Research*, 35(8), 1546-1550.
5. Kayali, O.; Haque, M.N.; and Zhu, B. (2003). Some characteristics of high strength fiber reinforced lightweight aggregate concrete. *Cement and Concrete Composites*, 25(2), 207-213.
6. Bhogayata, A., Shah, K.D., Vyas, B.A., Arora, N.K. (2012). Performance of concrete by using non recyclable plastic wastes as concrete constituent. *International Journal of Engineering Research and Technology*, 1(4). ESRSA Publications.
7. Kim, S.B.; Yi, N.H.; Kim, H.Y.; Kim, J.H.J.; and Song, Y.C. (2010). Material and structural performance evaluation of recycled PET fiber reinforced concrete. *Cement and concrete composites*, 32(3), 232-240.
8. Fraternali, F.; Spadea, S.; and Berardi, V.P. (2014). Effects of recycled PET fibres on the mechanical properties and seawater curing of Portland cement-based concretes. *Construction and Building Materials*, 61, 293-302.
9. De Oliveira, L.A.P.; and Castro-Gomes, J.P. (2011). Physical and mechanical behaviour of recycled PET fibre reinforced mortar. *Construction and Building Materials*, 25(4), 1712-1717.
10. Al-hadithi A.I. (2013). Improving impact and mechanical properties of gap graded concrete by adding waste plastic fibers. *International Journal of Civil Engineering and Technology* (*IJCIET*), 2(4), 118-131.
11. Mello, E.; Ribellato, C.; and Mohamedelhassan, E. (2014). Improving concrete properties with fibers addition. World academy of science,

engineering and technology. *International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering*, 8(3), 249-254.

12. Irwan, J.M.; Asyraf, R.M.; Othman, N.; Koh, H.B.; Annas, M.M.K.; and Faisal, S.K. (2013). The mechanical properties of PET fiber reinforced concrete from recycled bottle wastes. *Advanced Materials Research*, 795, 347-351.
13. Muttar, A.A. (2013). Improving the mechanical properties of no-fines concrete. *Journal of Babylon University/Engineering Sciences*, 2(21), 548-557.
14. Akçaözoğlu, S.; Atiş, C.D.; and Akçaözoğlu, K. (2010). An investigation on the use of shredded waste PET bottles as aggregate in lightweight concrete. *Waste Management*, 30(2), 285-290.
15. Ismail, Z.Z.; and Al-Hashmi, E.A. (2008). Use of waste plastic in concrete mixture as aggregate replacement. *Waste Management*, 28(11), 2041-2047.
16. Jo, B.W.; Park, S.K.; and Park, J.C. (2008). Mechanical properties of polymer concrete made with recycled PET and recycled concrete aggregates. *Construction and Building Materials*, 22(12), 2281-2291.
17. Rahmani, E.; Dehestani, M.; Beygi, M.H.A.; Allahyari, H.; and Nikbin, I.M. (2013). On the mechanical properties of concrete containing waste PET particles. *Construction and Building Materials*, 47, 1302-1308.
18. Al-Hadithi, A.I. (2008). Some properties of concrete using waste plastic fiber with very small percentages, *International Journal of Civil Engineering and Technology* (*IJCIET*), 93-101.
19. Dorf, R. (1996). Engineering Handbook. (2nd Ed.), New York, CRC Press.
20. Al-Manaseer, A.A.; and Dalal, T.R. (1997). Concrete containing plastic aggregates. Concrete International, 19(8), 47-52.
21. Saikia, N.; and de Brito, J. (2014). Mechanical properties and abrasion behaviour of concrete containing shredded PET bottle waste as a partial substitution of natural aggregate. *Construction and Building Materials*, 52, 236-244.
22. Akçaözoğlu, S.; Akçaözoğlu, K.; and Atiş, C.D. (2013). Thermal conductivity, compressive strength and ultrasonic wave velocity of cementitious composite containing waste PET lightweight aggregate (WPLA). *Composites Part B: Engineering*, 45(1), 721-726.
23. Kaiping, L.; Hewei, C.; and Jing'en, Z. (2004). Investigation of brucite-fiber-reinforced concrete. *Cement and concrete research*, 34(11), 1981-1986.
24. Batayneh, M.; Marie, I.; and Asi, I. (2007). Use of selected waste materials in concrete mixes. *Waste Management*, 27(12), 1870-1876.
25. Yang, S.; Yue, X.; Liu, X.; and Tong, Y. (2015). Properties of self-compacting lightweight concrete containing recycled plastic particles. *Construction and Building Materials*, 84, 444-453.
26. Imam, M. (2006). *Reinforced concrete - Properties and testing of hardened concrete*. (4th Ed.), Cairo.
27. Rebeiz, K.S.; Fowler, D.W.; and Paul, D.R. (1994). Mechanical properties of polymer concrete systems made with recycled plastic. *Materials Journal*, 91(1), 40-45.

28. Rebeiz, K.S.; Serhal, S.P.; and Fowler, D.W. (1994). Structural behavior of polymer concrete beams using recycled plastic. *Journal of Materials in Civil Engineering*, 6(1), 150-165.
29. Rebeiz, K.S. (1996). Precast use of polymer concrete using unsaturated polyester resin based on recycled PET waste. *Construction and Building Materials*, 10(3), 215-220.
30. Rebeiz, K.S., Yang, S. Fowler, D.W. (1994). Polymer mortar composites made with recycled plastics. *Materials Journal*, 91(3), 313-319.
31. Rebeiz, K. S., Fowler, D. W. (1996). Flexural strength of reinforced polymer concrete made with recycled plastic waste. *ACI structural journal*, 93(5), 524-530.
32. Silva, D.A.D.; Betioli, A.M.; Gleize, P.J.P.; Roman, H.R.; Gomez, L.A.; and Ribeiro, J.L.D. (2005). Degradation of recycled PET fibers in Portland cement-based materials. *Cement and Concrete Research*, 35(9), 1741-1746.
33. Hannawi, K.; Kamali-Bernard, S.; and Prince, W. (2010). Physical and mechanical properties of mortars containing PET and PC waste aggregates. *Waste Management*, 30(11), 2312-2320.
34. Foti, D.; and Paparella, F. (2014). Impact behavior of structural elements in concrete reinforced with PET grids. *Mechanics Research Communications*, 57, 57-66.
35. ASTMC597. (2004). *Standard test method for pulse velocity through concrete.* Annual Book of ASTM Standards.
36. Albano, C.; Camacho, N.; Hernandez, M.; Matheus, A.; and Gutierrez, A. (2009). Influence of content and particle size of waste pet bottles on concrete behavior at different w/c ratios. *Waste Management*, 29(10), 2707-2716.
37. Marzouk, O.Y.; Dheilly, R.M; and Queneudec, M. (2007). Valorization of post-consumer waste plastic in cementitious concrete composites. *Waste Management*, 27(2), 310-318.
38. Shayan, A.; and Xu, A. (2004). Value-added utilisation of waste glass in concrete. *Cement and concrete research*, 34(1), 81-89.
39. Ge, Z.; Huang, D.; Sun, R.; and Gao, Z. (2014). Properties of plastic mortar made with recycled polyethylene terephthalate. *Construction and Building Materials*, 73, 682-687.
40. Fletcher, I.A.; Welch, S.; Torero, J.L.; Carvel, R.O.; and Usmani, A. (2007). Behaviour of concrete structures in fire. *Thermal Science*, 11(2), 37-52.
41. Han, C.G.; Hwang, Y.S.; Yang, S.H.; and Gowripalan, N. (2005). Performance of spalling resistance of high performance concrete with polypropylene fiber contents and lateral confinement. *Cement and Concrete research*, 35(9), 1747-1753.
42. Mahdi, F.; Abbas, H.; and Khan, A.A. (2010). Strength characteristics of polymer mortar and concrete using different compositions of resins derived from post-consumer PET bottles. *Construction and Building Materials*, 24(1), 25-36.
43. Rebeiz, K.S. (1995). Time-temperature properties of polymer concrete using recycled PET. *Cement and Concrete Composites*, 17(2), 119-124.

44. Yesilata, B.; Isıker, Y.; and Turgut, P. (2009). Thermal insulation enhancement in concretes by adding waste PET and rubber pieces. *Construction and Building Materials*, 23(5), 1878-1882.
45. Dweik, H.S.; Ziara, M.M.; and Hadidoun, M.S. (2008). Enhancing concrete strength and thermal insulation using thermoset plastic waste. *International Journal of Polymeric Materials*, 57(7), 635-656.
46. Mounanga, P.; Gbongbon, W.; Poullain, P.; and Turcry, P. (2008). Proportioning and characterization of lightweight concrete mixtures made with rigid polyurethane foam wastes. *Cement and Concrete Composites*, 30, 806-814.
47. National ready mixed American association (2000). Flexure strength concrete, cip 16, 2000, from www.nrmca.org/aboutconcrete/cips/16p.pdf.
48. Ochi, T.; Okubo, S.; and Fukui, K. (2007). Development of recycled PET fiber and its application as concrete-reinforcing fiber. *Cement and Concrete Composites*, 29(6), 448-455.
49. Li, V.C.; Horii, H.; Kabele, P.; Kanda, T.; and Lim, Y.M. (2000). Repair and retrofit with engineered cementitious composites. *Engineering Fracture Mechanics*, 65(2), 317-334.
50. Siddique, R.; Khatib, J.; and Kaur, I. (2008). Use of recycled plastic in concrete: a review. *Waste Management*, 28(10), 1835-1852.
51. Xu, B.; Toutanji, H. A.; and Gilbert, J. (2010). Impact resistance of poly (vinyl alcohol) fiber reinforced high-performance organic aggregate cementitious material. *Cement and Concrete Research*, 40(2), 347-351.
52. Kakooei, S.; Akil, H.M.; Jamshidi, M.; and Rouhi, J. (2012). The effects of polypropylene fibers on the properties of reinforced concrete structures. *Construction and Building Materials,* 27(1), 73-77.
53. Byung-Wan, J.O.; Park, S.K.; and Cheol-Hwan, K.I. (2006). Mechanical properties of polyester polymer concrete using recycled polyethylene terephthalate. *ACI structural Journal*, 103(2), 219-225.