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Recycled Plastic as an Aggregate in Concrete

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Abstract Developing countries are suffering from the negative effect of accumulating local wastes and garbage, in which it increases the level of pollution, affects the public health and increases the percentage of epidemic [4]. Plastic waste often ends up in landfills or oceans for it is non-biodegradable and attempts to destroy it only result in more pollution. Repurposing of plastic waste into the construction industry is a way to decrease the amount of plastic waste, while simultaneously, limiting the over-dredging of sand and other natural materials. This research used experimental method to measure the effect of integrating plastic wastes in construction industry by reusing these plastic wastes and turning it into a useful cheap building material. The partial containment of repurposed plastics as aggregate in concrete mix is tested by experimenting the properties that arise when different percentages of plastic aggregate are used in a concrete mixture. The experimental program replaces cement with plastic at different percentages and the experiment revealed that replacing 10% of cement with plastic presents the better results as stated in this article. The specimens are tested and compared with a control specimen of 0% plastic in terms of compressive strength, unit weight and percentage of cracks. The results show that repurposed plastic aggregate in a certain percentage has no significant difference in the quality of the concrete. Therefore, polices mandating segregation and sorting of wastes for recycling and repurposing intentions should be issued so as to aid the use of these materials in more than one field, thus, saving the ecosystem.

Keywords Repurposed Plastic, Plastic Aggregate, Concrete Mixture, Lightweight Concrete

1. Introduction

Worldwide, the weight of the organic wastes that are produced every year is almost 38 billion metric tons [1, 2]. The dramatic increase in organic waste is due to human consumption rate, population explosion and the human behaviour. In Egypt, Almost 60 million tons of solid wastes are generated annually. According to Elfeki & Tkadlec (2015). The recycled organic waste in Egypt does not surpass 20%, the un-recycled organic waste will affect negatively the residents' public health and environmental so there is an urgent need to manage the rest of organic waste [3, 4, 5, 6]. The improper disposal ways of solid waste in drains, waterways, and opened dump sites have led to the contamination of water supplies and atmosphere which deters Egypt's heritage, natural resources, and the health & wellbeing of its residents [7].

Plastic waste is a huge global problem than can be controlled but not eliminated by the re-use of these plastic products. A study showed that 275 million tons of plastic waste were produced in 192 coastal countries among which 12.7 million tons of these disposed plastics were thrown in oceans resulting in detrimental effects on the environment [8]. If mandatory sorting process of Municipal solid waste (MSW) was applied, it would ease the repurposing or recycling of different waste materials to be used in building materials [4, 5, 9]. According to previous studies in the USA in 2018, plastic comprised about 13% of Municipal solid waste and about 18% of the wastes that were land filled [10,11]. These wasted materials can be used in construction as aggregate substitute [12]. Eventually this will reduce carbon dioxide emissions and reduce the amount of solid waste that will go to land filling. Previous studies discussed the properties of recycled plastic aggregates in concrete such as its effect on thermo-mechanical properties [13] and this study continues focusing on the compressive strength.

2. Materials and Methods

The Properties of Plastic Aggregate

The factors that have been previously studied in regards to the plastic aggregate particles added to concrete include;

- The kind of recycled polymer used
- Volume and size of plastic aggregate
- Mechanical properties
- Issues and advantageous properties that arise
- Applications

The following results were established:

The Kind of Recycled Polymer Used

The two types of plastics used in the following mentioned researches were post-consumer Polyethylene Terephthalate (PET) and Polyvinyl Chloride (PVC) plastics. Furthermore, these plastics were proven to be suitable and feasible types to use in certain construction projects [14].

The Volume and Size of Plastic Aggregate

PVC aggregates with the highest bulk density produced mixes with considerably higher compressive strength. A promising use of plastic aggregates requires the use of air-reducing agent as it has been observed that it compensates the strength lost due to the addition of plastic aggregate [14].

Thorneycroft et al. suggested that with suitable selection of the size and grading of plastic particle, it is possible to generate structural grade concrete mixtures with sand replacement of 10%. This percentage of sand replacement by a graded PET plastic of the matching size to the sand particles size provided the highest potential for the general performance. [15].

The overall concrete bulk density decreased upon utilization of the recycled plastic in the concrete. There was a reduction in the bulk density by 2.5 to 13% for the concrete mix that contains from 10% to 50% plastic aggregates that range from 10% to 50% made of recycled plastic when compared to the conventional counterpart [16].

Mechanical Properties

- Compressive strength

Unconfined Compressive Strength for the controlled sample was around 58 MPa after 28 days curing, whereas for 10% Recycled Plastic Waste was 38 MPa [8].

According to Thorneycroft, the concrete compressive strength decreased as the replacement percentages increased. Replacement levels of percentages ranging from 0 to 50% were examined, with a resultant decrease in strength being related to the percentage of substitution. A decrease of 15% in the average strength was recorded at 28 days with a 30% replacement percentage. These cutbacks in strength are credited to reduced bonding between the plastic and the adjoining cement paste. This comes as a conclusion maintained by most of the related research in the available literature [15].

When recycled plastic aggregates were added to concrete with percentages ranging from 10% to 50%, the resultant concrete mixture tests gave compressive strength readings between 48 and 19 MPa. It is apparent that the increase of the recycled plastic content resulted in a decrease in the value of the compressive strength. For the mentioned percentages of recycled plastic and decrease in compressive strength of 34% to 67% was registered [16].

This does not subdue the feasibility of the idea as investigating the mechanical properties of the resultant cement concluded that despite the diminution in such properties, the Plastic lightweight concrete (PLWC) containing 50 and 70% of Plastic lightweight aggregate PLWA displayed characteristics that made it meet the requirements for being employed as a lightweight construction material, 'class II structural concretes' as specified in the ACI-213 functional classification [17].

- Tensile Strength

For the concrete produced by adding post-consumer plastic aggregates, testing its Splitting tensile strength determined that it decreased when the percentage of plastic aggregates increased. 17% of the tensile strength decreased after adding 10% plastic aggregates to concrete. The splitting tensile strength displayed a decrease when w/cm increased for a certain plastic aggregate content [16].

Issues and Advantageous Properties that Arise

- Issues

When sand is substituted in concrete by waste plastic its density and compressive strength are reduced. Perhaps the poor bonding between the added plastic and the surrounding concrete is the reason, as we find due to the hydrophobic nature of the plastic surface, excess water gathers increasing the voids [15].

- Advantageous aspects

Plastic aggregate use gave rise to two useful properties of reduced thermal conductivity and water adsorption capacity compared to regular concrete. These properties can be of a great prospective for thermal insulation and impermeable concrete applications purposes respectively [14].

A better behavior with regards to ductility was displayed by the concrete which contains plastic aggregates when compared with the concrete containing conventional aggregates. Increase in ductility is considered an important advantage as it reduces cracks development and propagation [16].

Moreover, it was found that upon an increase in the replacement ratio of the Plastic Lightweight Aggregate (PLWA), there was a resulting improvement in the workability of Plastic Lightweight Concrete (PLWC). The workability improvement of PLWC resulted in a diminution of the unit water content and the water-reducing agent content to improve strengths.

It also found out that there was a reduction in the density of the concrete that contained recycled Plastic Lightweight Aggregate PLWA, where the concrete mixture with the higher replacement level displayed the lower density value.

Another benefit for the mixture properties is the improvement of the resistance to chloride ion penetration after replacing a percentage of sand by PLWA; steel reinforcement protection against corrosion is enhanced when this property of resistance is higher. This puts forward utilization of PVC aggregate in construction materials that are used in harsh environmental circumstances that cause material deterioration [17].

Applications

As stated by Siddique, conventional aggregate can be replaced successfully by post-consumer plastic aggregates [16].

For precast applications, it was determined that using an unsaturated polyester resin based on recycled PET was possible for polymer concrete. More than 80% of the ultimate strength of the material was achieved in one day. This represents a noteworthy advantage in construction applications. The presented product is considered as a\ good-quality of polymer mortar [16]

Mixed plastic particles that milled, shredded mixed plastic, and melt-processed plastic fibers can be used to produce discrete reinforcement for concrete. The resultant concrete mix displayed better properties in the following aspects:

- More resistance of concrete to impact.
- More resistance to shrinkage micro-cracking.
- More impermeability.
- More resistance to de-icer salt scaling.

Conversely, the abrasion resistance of concrete decreased with the addition of recycled plastic [16].

There are many application field where recycled plastic can be successfully utilized such as:

Repair and superimposition of damaged concrete planes made of cement ranging from pavements, and flooring, to complex nature project as surfaces within bridges, dams and barriers.

Precast concrete applications in elements within different utility structures. Examples that are related to water service such as acid wastes drains, sewer pipes, and underground vaults. Other examples that are related to power systems such as junction boxes and pre-stressed concrete poles for power line transmission projects. Different elements within the transportation sector such as highway crash strips or barriers, panels of bridges, in addition to railway crossties. Different components within marine construction [16].

Upon analysing the different material properties of concrete mixtures that contain partial substitution of normal aggregate by PVC wastes, it is determined that this is feasible as a new solution with ecological advantages from both the economical and energy conservation perspectives [17].

This comes although, it was asserted that mechanical properties of these innovative concrete mixtures is inversely proportional to the amount of recycled plastic aggregate [18, 19]. One of the reasons for this finding is that bonding of plastic to the surrounding cement paste is decreased due to the hydrophobic nature of plastic, hence, the produced concrete has lower mechanical properties as compressive and tensile strength. But, using graded plastic aggregate preferably Polyethylene terephthalate (PET) or Polyvinyl chloride (PVC) in low percentages (10%) with a treatment of the plastic particles to advance the bond between cement and particles yields the best results and can successfully be used in concrete production [14].

3. Methodology

This research used experimental method to determine the compressive strength in the early stages i.e. after 7 days curing of a concrete block with 10% post-consumer plastic aggregate by weight. Post-consumer plastic (Polyethylene terephthalate) water bottles have been collected and manually cut into approximately 1x1 cm squares.

A 10x10x10 cm cube mould was used to make two concrete blocks where one is the control and the other block has the same amount of water, cement and sand as the control. The difference between the two cubes is the 10% (by weight) of coarse aggregate that has been replaced with plastic in the second experimental cube. Furthermore, the cubes were put in water for curing for 7 days, and then were tested for compressive strength.

This method was chosen to further confirm the feasibility of using plastic waste as aggregate using experiments testing the effect of size and percentage replacement on the properties of concrete containing plastic waste.

(Source: image credits by author @ 2020)

Figure 1. 1x1 cm plastic aggregate

4. Results

(Source: image credits by author @ 2020)

Figure 2. Concrete cubes after one day (Left) specimen with plastic aggregate- (right).

(Source: image credits by author @ 2020)

Figure 3. Concrete cubes after seven days (Left) specimen with plastic aggregate- (right)

The mixture were made, and it was casted into a box moulder and compacted. A day after that, the concrete boxes were checked, it was noticed that the concrete block with plastic aggregate had many pores in the middle sections as well as in the side faces and in the top and bottom formed solid sections as illustrated in Figure 2.

After 7 days (Figure 3), upon close observations the plastic on the surface seemed to be easily chipped away if pulled and this is due to Polyethylene terephthalate (PET) hydrophobic nature.

The two cubes were then put in water for curing for the next 7 days (Figure 4).

(Source: image credits by author @ 2020)

Figure 4. Curing of concrete cubes (Left) specimen with plastic aggregate- (right)

After 7 days, the cubes were put under a compression strength test in early stages (Figure 5& Figure 6).

(Source: image credits by author @ 2020)

Figure 5. Control cube under compression test

(Source: image credits by author @ 2020)

Figure 6. Failure area in control cube

Table 1. Compressive strength test readings for control cube

Sample failure readings	
sample peak load	154.7kN
sample stress	15.47Mpa
pace rate	3.00kN/sec

As shown in Figure 7, compressive strength for the control block was measured to be 15. 47 Mpa as shown in Table 1.

(Source: image credits by author @ 2020)

Figure 7. Specimen cube containing plastic aggregate under compression test

(Source: image credits by author @ 2020)

Figure 8. Failure area in specimen cube containing plastic aggregate

Table 2. Compression strength test readings for specimen cube containing plastic aggregate

Sample failure readings	
sample peak load	52.7kN
sample stress	5.26Mpa
pace rate	3.00kN/sec

Compressive strength for the specimen block was measured to be 5.267 Mpa as shown in readings in Table 2.

These tests have shown that there was a 66% decrease in compressive strength only in the early stages for a 10x10x10cm cube using only 10% post-consumer plastic (Polyethylene terephthalate) plastic aggregate of about 1x1cm by volume as shown in Figure 8. In previous researches the percentage decrease in strength was much lower for 10% plastic aggregate.

5. Conclusions & Recommendations

To conclude this research, it has been confirmed that adding plastic aggregate reduces compressive strength but the manner in which the concrete formed a more solid section at the top and bottom sections of the cube needs further investigation. Furthermore, smaller plastic aggregate size replacing normal aggregate by 10% volume will be more efficient and will allow the plastic to mix better with the cement as well as increase workability. Also, compaction needs to be done by machine in the plastic aggregate mix as manual compaction was not sufficiently efficient.

The tests done in this research are premature and further tests need to be done testing different plastic size and dimensions, different percentages of plastic used and using larger moulds to make the tests more accurate.

Problems that have come up during the tests were that the plastic aggregate mix did not fit into the mould entirely even after manual compaction. Machine compaction may be needed in future tests. Furthermore, the plastic is hydrophobic and smaller plastic size may minimize this problem.

If these tests are further improved taking into consideration all the previous points and improvements, plastic aggregate can be considered as a promising field in the construction industry, by recycling plastic and reusing it as an additive in construction materials.

Governments should mandate segregation as a major step in solid waste management. This step will promote recycling and reusing until they become compulsory by law. This work provides potentially ecological and economical benefits as it will most importantly help save the planet as well as other benefits from being used in different sectors including the huge construction materials industry.

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