Effectiveness of Using Plastics Granules and Manufactured Sand in Concrete Production

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Abstract

This paper investigated the effectiveness of using plastics granules and manufactured sand in concrete analysis. We knew vividly that Plastic bottles constitute major solid waste and its problem of disposal. Replacement of aggregates by waste materials for concrete has proved to be an effective technique in tackling the problem of wastes management. The areas studied in this work include the compressive strength of the concrete specimens, and the slump analysis to determine the workability of the concrete. Parameters considered in this work include mix design in which cement x = 480kg/m^3 water = 180kg/m^3, fine aggregate = 530kg/m^3, and the coarse aggregate = 1230kg/m^3 with water to cement ratio of 0.40. In replacing partially, the quantity of manufactured sand with plastic granules, the quantity of plastic granules was varied against the manufactured sand at an interval of 0%. 2%, 4%, 6%, 8%, and 10%. The compressive strength specimens were tested at curing age of 7, 14, and 28 days. The results showed that the compressive strength development at various percentage replacement of manufactured sand with plastic granules at level of 0%, 2%, 4%, 6%, 8%, and 10% plastic particles on the 28 days are 36.24Mpa, 30.08 Mpa, 26.56 Mpa, 25.10 Mpa, 23.59 Mpa, and 22.89 Mpa respectively. In conclusion, the incorporation of plastic granules into concrete production helps to reduce the overall density of concrete, making it lighter and more easily workable during construction. Additionally, the plastic granules act as a filler material, enhancing the concrete's resistance to cracking.

Keywords: plastic granules, concrete, manufactured sand, aggregate (fine and coarse), and density.

Introduction

Plastic granules play a significant role in modern concrete production, as they offer a sustainable and innovative solution to enhancing the properties of concrete. The utilization of plastic granules in concrete not only addresses plastic waste management issues but also improves the mechanical and durability characteristics of the final construction material (Shalini et al, 2018). The incorporation of plastic granules helps to reduce the overall density of concrete, making it lighter and more easily workable during construction. Additionally, the plastic granules act as a filler material, enhancing the concrete's resistance to cracking and increasing its flexural strength (Saurabh, 2020). Moreover, the use of plastic granules in concrete production aligns with the global initiative to promote sustainability and reduce the environmental impact of construction activities. By reusing plastic waste in concrete, we can minimize the consumption of natural resources and contribute to a greener and more eco-friendly building industry. In essence, the integration of plastic granules in concrete production demonstrates a promising pathway towards the development of sustainable and high-performance construction materials (Fayad, 2018).

Concrete is a stone like material that has a cementitious medium within which aggregates are embedded. It is an extraordinary and key structural material in the human history. It consists of three phases, i.e. aggregate phase, hydrated cement paste (HCP) and interfacial transition zone (ITZ). As written by Brunauer and Copeland (2006), "Man consumes no material except water in such tremendous quantities". It is no doubt that with the development of human civilization, concrete will continue to be a dominant construction material in the future. However, the development of modern concrete industry also introduces many environmental problems such as pollution, waste dumping, emission of dangerous gases, depletion of natural resources etc. The construction industry today relies much on sand as fine aggregate in concrete production; also, the demand of sand is constantly increasing. Continuous mining of sand has led to soil deterioration and environmental pollution.

The construction industry today relies much on river sand as fine aggregate in concrete production, and as a result the demand for river sand is constantly increasing. Continuous mining of sand will lead to soil deterioration and environmental pollution. Concrete is one of the most common construction materials which require a large quantity of natural resources and some of these resources used in concrete production include sand, gravel, lime stone, crushed stone, water and cement. The recent rapid development in urban area around the world is increasing whereas natural resources are reducing in an increasing rate. Therefore, there is need for the usage of alternative materials like plastic waste for partial replacement of sand in concrete production. This is the basis of this work.

The aim of the study was to determine the effectiveness of using plastic granules and manufactured sand as fine aggregate in concrete production. And to achieve this goal, we set out the following objectives.

i. To investigate how replacing different quantity of manufactured sand in a standard concrete mix with plastic particles of similar size will affect the characteristic strength of concrete.

ii. To determine whether plastic particles replacement of manufactured sand in concrete could be a sustainable alternative to conventional concrete.

iii. To investigate at what level of replacement comprehensive strength became maximum using plastic as fine aggregate replacement in concrete.

The investigation of the effectiveness of using plastics granules and manufactured sand in concrete production reported in this work was carried out using water cement ratio of 0.40 and mix ratio of 1:1.5:3, at various replacements level of 0%, 2%, 4%, 6%, 8% and 10% plastic granules materials with manufactured sand as fine aggregate in the concrete preparation. Parameters tested in this work are weight of the cube, slump value, and the compressive strength value.

Significance of Study

The investigation of using granules and manufactured sand in concrete production is significant for its potential to drive sustainable innovation, improve construction practices, and enhance the performance and environmental profile of concrete structures. It addresses critical questions concerning material efficiency, structural integrity, and environmental impact, paving the way for a more sustainable and resilient built environment. Also, the work is a step in understanding the workability, and compressive strength of concrete produce using plastic waste in partial replacement of manufactured sand as fine aggregate in concrete production. This is to guide users of these materials (plastic materials) on their strength effectiveness.

Literature Review

In today's construction industry, there is a growing need for alternative techniques to improve the properties of concrete. Concrete is a hardened mass obtained from a mixture of

cement, sand, gravel and water in definite proportions. These ingredients are mixed together to form a plastic mass which is poured into desired shape moulds called forms. The chemical reaction between cement and water lead to the hardening of the mixture and plain concrete thus formed. Concrete has good compressive strength but very little tensile strength, thus limited its uses in construction. Plain concrete is used where good compressive strength and weight are the main requirements and tensile stresses are very low (Neelam, 2009). An attractive option is the replacement of fine and coarse aggregate with other structural attractive materials. Given the environmental impact of plastic waste, globally, the management of plastic waste is seen as a serious environmental issue (Youcef, 2015). The growing rate of urbanization and industrialization has increased the demand for concrete materials, and the construction aggregate has exceeded 10 billion tons per annum (Kumar et al., 2011), prompting growing research for the use of plastic waste as an aggregate in mixture concrete. Literature on the use of Polypropylene (PP) waste in concrete is heavily concentrated on adding PP coarse in mixture concrete. However, a few numbers of studies have initiated using it as a fiber in mixture concrete.

Plastics have become an inseparable and integral part of our lives. The number of plastics consumed annually has been growing steadily. In India approximately 40 million tons of solid waste is produced annually. This is continuously increasing at the rate of 1.5 to 2% every year (Akeaozoglu, 2010). Plastics constitute 12.3% of total waste produced most of which is from discarded water bottles. The Poly-ethylene Terephthalate (PET) bottles cannot be just disposed of by dumping or burning, as they can produce uncontrolled fire or contaminate the soil and vegetation. Its low density, high strength, fabrication capabilities, user friendly designs, long life, light weight, and more importantly low cost are the factors behind such phenomenal growth. Plastics have been used in automotive and industrial applications, packaging, medical delivery systems, other healthcare applications, land/soil conservation, preservation and distribution of food, communication materials, security systems, and some other uses. With such large and varying applications, plastics dominantly contribute to an ever-increasing volume in the solid waste stream. In 2007, it was reported a world's annual consumption of Poly-ethylene Terephthalate (PET) drink covers of approximately 10 million tons, which presents perhaps 250 million bottles. This number grows about up to 15% every year. On the other hand, the number of recycled or returned bottles is very low. The empty PET packaging is generally discarded by the consumer after use and becomes PET waste (WPET). The major problems that this level of waste production generates initially entail storage and elimination. Hence an attempt on the utilization of waste Poly-ethylene Terephthalate (PET) bottle granules as fine aggregate is done and its mechanical behaviour is investigated.

The daily use of plastic has increased enormously, resulting to high number of Plastic wastes (PW) in millions of tons, and Plastic wastes (PW) is expected to reach 2.2 billion tons by 2025 (Han et al., 2005). Therefore, effective ways of utilizing Plastic wastes (PW) must be explored to improve ways of Plastic wastes (PW) recycling. The use of recycled plastic as an aggregate has gained recognition as a promising technology capable of contributing to resource efficiency in the construction industry. Using Polypropylene (PP) waste plastic in particular as a construction material has attractive qualities because of its composition, in addition to the environmental and financial benefits. More recently, using Polypropylene (PP) as an aggregate for mixture concrete is explored by researchers around the world (Kakooei et al., 2012; Mazaheripour et al., 2011). Polypropylene has some properties which will contribute greatly to structural stability. Polypropylenes have some crack resistance performance (He et al., 2011) that will contribute to improving structures. PP achieves great water proof through crack resistance. Therefore, infusing PP into concrete mixture can reduce early contraction deformation of concrete, hence improving impermeability of the concrete (Wong, 2004). Light weights concrete was emerged as a promising modern technology with the rapid development of floating marine, high rise buildings and long span concrete structures. These are all credited to the excellent characteristics of lightweight concrete such as high specific strength, lower density, better

thermal insulation and better energy absorption by replacing normal aggregate partially or totally with light weight aggregate such as PP (Xu et al., 2012).

In this paper, the attention was focused on the use of PET granules incorporated in concrete as partial substitution of an equivalent weight of fine aggregate that is manufactured sand.

Materials and Methods

Materials and properties

i. Plastic Granules

The plastic bottle waste known as Poly-ethylene Terephthalate (PET) was used in this work; it was used to partially replace the fine aggregate content (manufactured sand) in the proportion of 2%, 4%, 6%, 8%, and 10%. The main considerable property of this element was its low density.

ii. Coarse Aggregate

Coarse aggregate of size 20mm and specific of 2.90 was used in this research, the aggregate was retained on a 5.0 mm test sieve and containing no finer material than is permitted in BS 882: 1992 (BS 882:1992). It was gotten from Iyukhu quarry site, Auchi, Edo State.

iii. Fine Aggregate

Manufactured sand which is often gotten from crushed rock was used in this work. It is made up of tiny grains of stone and other minerals. It was obtained from Iyukhu quarry site, Auchi, Edo State.

iv. Cement

The Bua brand of cement was used in this work. It is a grey finely grinded powder substance and it has a property of effective hydration in water. The Bua cement is manufactured in accordance with the requirement of BS12: 1989.the grade 43.5.

Methodology

Concrete mix Design

Often concrete mix is designed to give the specified strength at minimum cost. The cost depends upon the value of the materials and labour required for batching, mixing, transporting, placing, compaction and toweling and the method of curing adopted.

Table 3.1 Mix Design for 1m3 of concrete with water cement ratio 0.40

A-1	**Stipulations for Proportioning for concrete mix**	
1	**Grade Designation**	**C40**
A-9	**Mix Proportions for One Cum of Concrete (SSD Condition)**	
1	Mass of Cement in kg/m3	450
2	Mass of Water in kg/m3	180
3	Mass of Fine Aggregate in kg/m3	530
4	Mass of Coarse Aggregate in kg/m3	1230

Preparation of Specimen

The research is to investigate the effectiveness of plastic granules inclusion as a partial replacement of manufactured sand on the compressive strength of concrete. Concrete cube of size 150 x150 x 150mm was used in the study. The coarse aggregate in the mix was of the sized 20mm granite. The batching of concrete was done by weighing the different constituent materials based on the adopted mix design with water cement ratio of 0.40. The fine aggregate (sand) portion of the mix was partially replaced with plastic (grounded) at six level of sand replacement. The levels of sand replacement are 100% sand: 0% plastic (control experiment),

98% sand: 2% plastic, 96% sand: 4% plastic 94% sand: 6% plastic 92% sand: 8% plastic, and 90% sand: 10% plastic. They were mixed together with the aid of a shovel and in the course of mixing, the corresponding quantity of water was added, when the mixture had been mixed to a homogeneous state, the mixture was poured into a head pan. 150mm x 150mm cubes were cast. This was to test the average compressive strength of concrete for this study. Each mould was filled with concrete in three layers using a trowel. And each of this layer was compacted using a 20mm diameter tamping rod to tap 25 times in accordance with BS 1881(15) After demoulding, the specimens were then transferred into a curing tank that contains clean water where they were store till 7, 14, and 28 days before compressive test was carried out.

Tests on the Concrete

Test on Fresh Concrete

Fresh concrete is simply concrete whose components are fully mixed but its strength has not yet developed. It is a period of complete hydration. The properties of fresh concrete directly influence the handling, placing and consolidation, as well as the properties of hardened concrete. ASTM makes provision for sampling of concrete. It spells out the procedures for sampling various production systems like the Slump test and compacting factor ratio test.

Slump Test

Apparatus

i. The metal mould for the slump test was a frustum of a cone, 305mm high, open at both ends. The base of 203mm diameter was placed on a smooth surface with smaller opening of 102mm diameter at the top.
ii. A 610mm long bullet nosed metal rod, 16mm in diameter.
iii. Spirit level
iv. Trowel
v. Measuring tape

Procedure

The slump cone is filled with concrete in three layers using the trowel. Each layer was tamped 25 times with a standard steel rod and the top surface is struck off by means of screeding and rolling motion of the tamping rod. I made sure that the mould was firmly held against its base during the entire operation; this is facilitated by handles or foot-rests brazed to the mould. Immediately after filling, the cone is slowly lifted and the unsupported concrete slumped - hence the name of the test. The decrease in the height of the centre of the slumped concrete is called slump and measured with the spirit level to the nearest 5mm. If the slump is <100mm and measured to the nearest 10mm if the slump is >100mm.

Test on the Hardened Concrete

The type of test that was done on concrete cubes was the compressive strength test and the cubes were tested for 7, 14, 21 and 28 days.

Analysis of Results

Workability:

The ability of concrete by which it can be mixed, transported, placing and compacting is known as workability.

Slump test

Ingredients of mixes were properly mixed so as to produce homogeneous and uniform fresh concrete in macro scale in order to know its workability using slump test.

Table 1: Slumps and Compacting Factor Ratio tests results

Various percentage replacement of fine aggregate with plastic granules	Slump value(mm)	Compacting factor ratio
0%	12mm	0.78
2%	30	0.82
4%	25mm	0.86
6%	70mm	0.62
8%	collapse	0.61
8%	collapse	0.56

Compressive Strength of Concrete Cubes:

Note before testing the concrete cubes, the weights of all the composite were recorded on a scale. And the compressive strength test was done to determine the strength of concrete mix prepared. The test was conducted on the 7, 14 and 28 day and their observations were shown below in figure 4.1 to 4.7

Table 2: Rate of compressive strength development at 7 days for the various percentage replacement of manufactured sand with plastic particles

% replacement of plastic	control	2%	4%	6%	8%	10%
Weight of cube (kg)	8.30	8.25	8.12	8.05	7.90	7.72
`compressive strength (N/mm2)	24.07	22.31	18.30	19.05	17.20	15.91

Table 3: Rate of compressive strength development at 14 days for the various percentage replacement of manufactured sand with plastic particles

% replacement of plastic	control	2%	4%	6%	8%	10%
Weight of cube (kg)	8.30	8.25	8.12	8.05	7.90	7.72
`compressive strength (N/mm2)	31.35	26.98	25.40	27.20	21.9	19.9

Table 4: Rate of compressive strength development at 28 days for the various percentage replacement of manufactured sand with plastic particles

% replacement of plastic	control	2%	4%	6%	8%	10%
Weight of cube (kg)	8.30	8.25	8.12	8.05	7.90	7.72
`compressive strength (N/mm2)	36.24	30.08	26.56	25.10	23.59	22.89

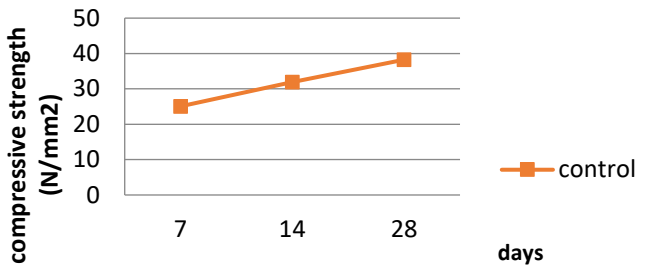


fig 4.1 Rate of compressive strength development for the control experiment

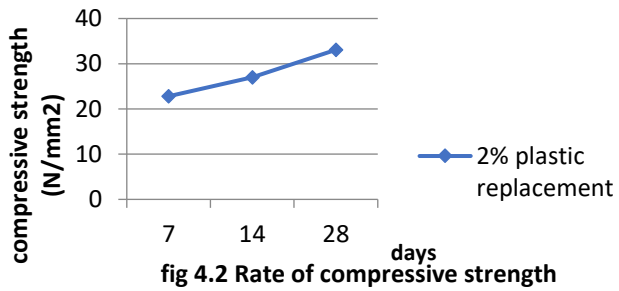


fig 4.2 Rate of compressive strength development for 2% plastic replacement

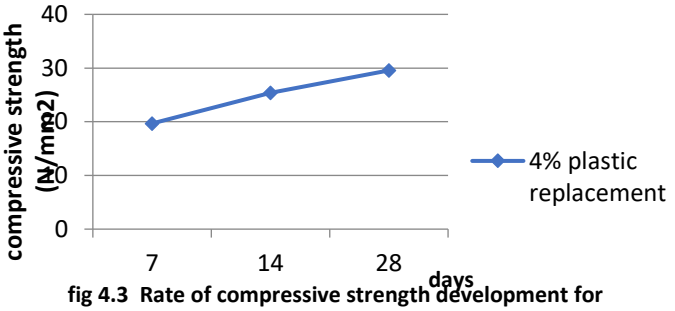


fig 4.3 Rate of compressive strength development for 4% plastic replacement

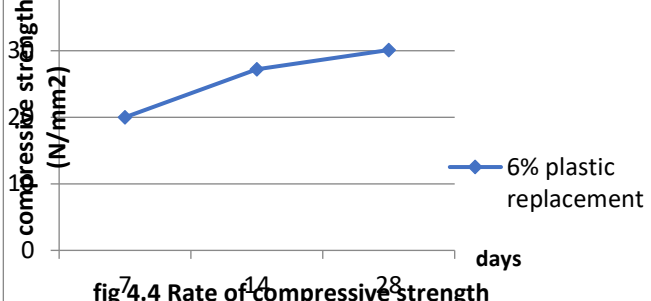


fig 4.4 Rate of compressive strength development for 6% plastic replacement

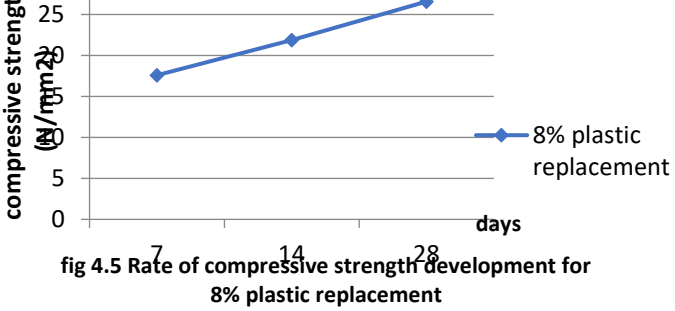


fig 4.5 Rate of compressive strength development for 8% plastic replacement

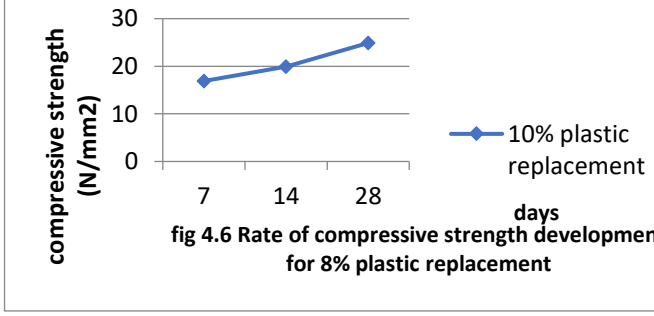


fig 4.6 Rate of compressive strength development for 8% plastic replacement

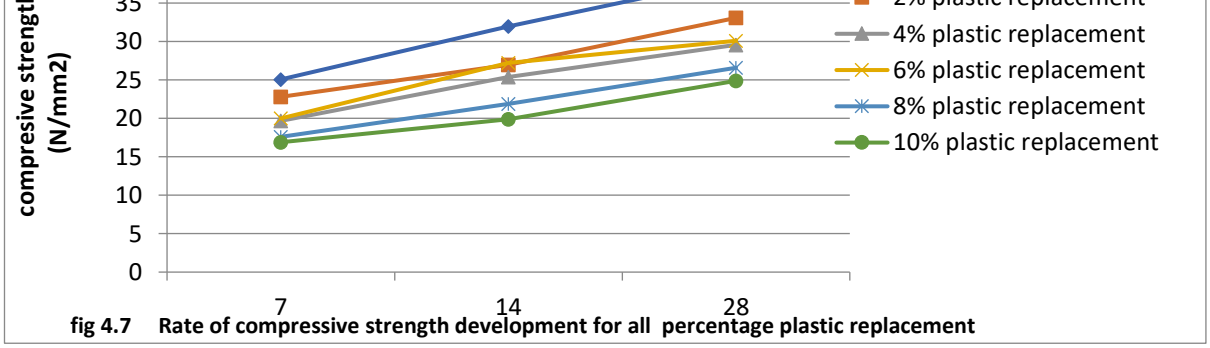


fig 4.7 Rate of compressive strength development for all percentage plastic replacement

Discussion of Results

A number of tests were conducted and the results were summarized in figure 4.1 to 4.7 above. From the concrete proportions with water cement ratio of 0.40 and concrete mix was designed with compressive strength of 40 MPa for 28 days. The compressive strength development at various percentage replacement of manufactured sand with plastic granules at level of 0%, 2%, 4%, 6%, 8%, and 10% plastic particles on the 28 days are 36.24Mpa, 30.08 Mpa, 26.56 Mpa, 25.10 Mpa, 22.59 Mpa, and 19.89 Mpa respectively due to increase in plastic granules in the mix of cement in the concretes. This results in line with work of previous researchers like Akeaozoglu (2010) and Saurabh et al (2020). The general failure modes of all the concrete specimens were represented by cracks development. Cracks in the concrete specimens are formed generally in regions where the compressive stresses exist and exceed the specified strength of the concrete. It shows the water cement ratio during the mix increases as the quantity of plastic granules increases, and this was due to negligible absorption of plastic aggregate and as result water was saved during the laboratory work.

Conclusion

Findings revealed that the use of plastic particles in concrete production provide an alternative way for reducing the impacts of disposing plastics waste. The inclusion of various percentages of plastic granules into concrete paste lower gradually the compressive strength value, and also drop in the weights of the composites at the various percentage level of plastics particles when check with conventional concrete. This made the concrete structure lighter, as a result of light weight properties; it can be used for high rise building for non-structural members. The incorporation of plastic granules helps to reduce the overall density of concrete, making it lighter and more easily workable during construction. Additionally, the plastic granules act as a filler material, enhancing the concrete's resistance to cracking and increasing its flexural strength.

Recommendation

The hydration properties in this investigation were studied up to an age 28 days. However, there is a need to investigate these at a later age. There should be investigation into high percentages (up to 30%) of plastic granules as a replacement to manufactured sand, in order to measure their effect on the physical and mechanical properties of normal concrete.

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