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Mechanical Strength, Characterization and Suitability of Cement-Plastic Concrete Admixture

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ABSTRACT: A significant increment in the consumption of plastic has been monitored globally in recent years, which has led to a high amount of plastic waste. Given its benefits on both an economic and ecological level, recycling plastic waste to create new materials like concrete is considered to be one of the finest ways to get rid of plastic waste. The objective of this paper was to examine the workability, durability, and mechanical strength of concrete with partial replacement of coarse aggregates with plastic waste using standard procedure. The percentages of plastic waste used to replace coarse aggregate were 0%, 5%, 10%, and 15%. Lastly, the mechanical characteristics of the concrete mix specimens was determined by testing them using a testometric and compressor machine. The specimens are then compared with the conventional mix. The test results demonstrated that the compressive strength exhibited a decreasing trend. For mixes ranging from 0% to 15%, the compressive strength varies from 35.66 to 17.88 N/mm2, however the flexural strength significantly decreases when 15% of the coarse aggregate is replaced with plastic waste. It can be concluded that reusing plastic waste as an aggregate during the concrete-making process reduces waste and conserves resources.

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Concrete is a versatile material that can be mold into different shapes, and is widely used for construction activities all over the world as it gives a good durability property to the structures which it forms (Ohwofasa *et al.*, 2023).

When added to raw earth materials, plastic wastes have the potential to improve waste management from a circular economy standpoint and enhance the mechanical and physical properties of newly developed sustainable construction materials (C Monica *et al.*, 2023). The construction industry is currently the primary driver of environmental degradation, global warming, and climate change, accounting for 50% of carbon emissions, 20% to 50% of energy and natural resource use, and 50% of total solid waste generation (I Vasilca *et al.*, 2021). Because of this, researchers are growing more interested in alternative building materials derived from renewable resources (A Bonoli *et al.*, 2021). Statistics show that every person contributes to the daily increase in solid waste, which includes plastic, as a result of the high rate of individual consumption. Plastic waste is an international issue. In comparison to the 1950s, when usage of plastic was roughly 5 million tonnes, more than 100 million tonnes are consumed annually worldwide (S Vigneshwaran *et al.*, 2020). In African nations, one-third of the waste produced is not

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collected. Because of this, the wastes are frequently combined with human and animal faeces and deposited carelessly on roadways and water sources, which causes flooding, creates habitats for insects and rodents, and spreads illness (G Linda *et al.*, 2019). Plastic waste will continue to pollute the environment for many years; this is an unavoidable problem in the modern world. There must be a quick fix for this problem. Utilising plastic waste in the construction of concrete is one of the numerous strategies that have been proposed to reduce waste products, and it may help to some extent with environmental issues (O Kehinde *et al.*, 2020).

Natural resources are being depleted as a result of the requirement for concrete in construction, which harms the environment. Researchers began examining potential replacements for natural aggregates and binding materials with plastic wastes to address this problem. Concrete is the most commonly used building material worldwide. It is composed of cement, sand, water, coarse aggregates, and other inert ingredients. An estimated 30 billion tonnes of concrete are produced each year, and the number is expected to increase as worldwide per capita consumption is predicted to be over three times larger than it was forty years ago (KS Ali *et al.*, 2023). Aggregates play a major role in the fresh and hardened properties of the cementations matrix; they typically comprise 65–80% of the concrete's total volume (S Nabajyoti and dB Jorge, 2012).

Therefore, the possibilities for utilizing waste plastic in concrete mixes have been examined and compared with control samples in this study. Due to high labour costs and the limited amount of plastic that can be recycled and repurposed from the plastic waste, a significant amount of plastic waste is produced annually, which causes serious environmental problems. The majority of plastic waste ends up in landfills, incinerators, and dumps, which are not the most efficient ways to manage plastic waste. This brings us to the study's focus: improving the qualities of concrete by incorporating these plastic wastes as plastic aggregate. The objective of this paper was to examine the workability, durability, and mechanical strength of concrete with partial replacement of coarse aggregates with plastic waste.

MATERIALS AND METHODS

Dangote Portland limestone cement (PLC), CEM II 42.5R (B-L), conforming to the specifications laid by British Standards - (BS EN1971, 2011) was used as the main binder for concrete mixing, which is commercially available. The research methodology's process tree, from material collection to study conclusion, is depicted in Fig. 1.

Table 1. Fineness analysis on (50g) of Cement

S/N	Siev Size (μm)	Percentage Retained (%)
1	90	6.5
2	Pan	93.0

The Potable water available in the laboratory was used for mixing and curing of concrete. The fine natural sand for the concrete was sourced locally in University of Ilorin, confirming to IS 383-1970. Crushed granite stone with nominal size 5mm to 20mm, suitable was used as coarse aggregate confirming to IS 383-1970. Sieve size analysis was conducted in accordance to IS 383-1970. Plastic waste (HDPE) obtained from old/discarded waste, cleaned to remove foreign objects. It was exposed to the sun for a short while, the plastic was then crushed into tiny pieces.

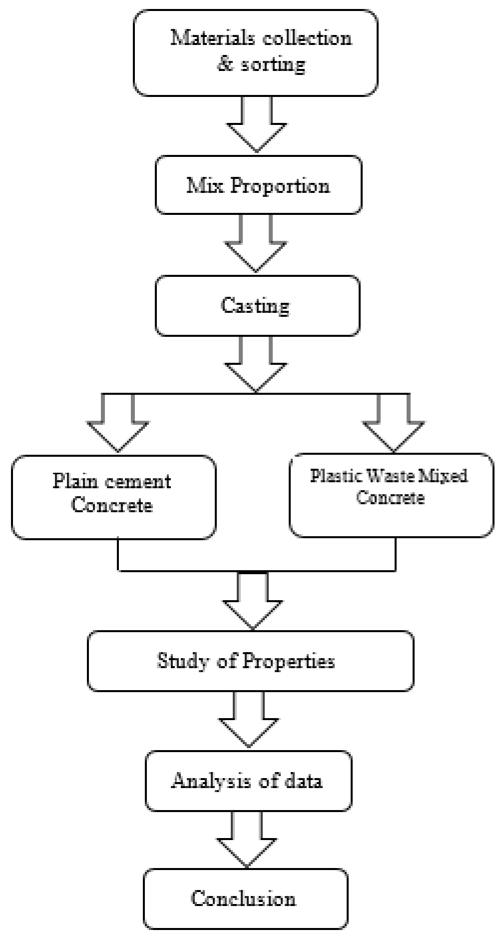

Fig. 1. Process tree for research methodology

Grade M20 was used to prepare the mix design, with mix a ratio 1:1.5:3:0.55. It was used throughout the experimental investigation. Table 2 shows the amount of concrete ingredients required for M20 Mix for 1m^3 As per IS 10262-2009. The Volume of the materials was calculated, to avoid shortage after compaction, 0.002m^3 was added to the volume. By multiplying the required volume by their densities (cement: 1440 kg, fine aggregate: 1600, coarse aggregate: 1650), the required volume was converted to weight. Calculating the weight of cement, multiplying by the water-cement ratio (which is 0.55), and the amount of water was determined.

Casting: Table 3 and 4 shows the replacement approach for both cube and beam sizes. The mix design substitutes plastic waste for coarse aggregate at a weight of 0%,5%, 10%, and 15% was created. Three cubes and three beams were cast for every percentage. Three cubes measuring 100 mm by 100 mm × 100 mm were formed for each different percentage of plastic concrete, and three beams measuring 100 mm by 100 mm × 500 mm were produced for each different percentage of plastic replacement. A balance was used to measure the cement, sand, coarse aggregate, and plastic aggregate. A measuring cylinder is used to measure the water. To create a uniform concrete mix, all necessary material weights are manually mixed for five minutes. Fig. 2. Shows the Crushed waste plastic mixed with cement, fine aggregate and coarse aggregate. After a predetermined amount of drying time, the concrete mixes are removed from the mould and immersed in water for seven and twenty-eight days to cure and test their stability. One of the most important stages in strengthening concrete is curing, which keeps the material from losing moisture while it hydrates. Compressive and flexural strength tests were performed on the hardened concrete. Testing was done on the specimens after 7, and 28 days of cure. The characteristics were contrasted with the reference concrete. Fig. 3. Shows the cube specimens after 7 and 28 days curing.

Table 2. The quantity of M20 Mix concrete materials needed for a 1m^3

Ingredients	Cement	Fine aggregate	Coarse aggregate	Water
Quantities, kg	403	672	1218	220
Ratio by weight	1	1.81	3.68	0.55
Size/Properties	Specific gravity (3.15)	size (5 mm)	size (20 mm)	

Table 3. For a 100 x 100 x 100 cube, substitution of a portion of the coarse aggregate with plastic percentages.

Materials(kg)	Plastic waste replacement		
	5%	10%	15%
Cement	0.864	0.864	0.864
Plastic aggregate	0.155	0.310	0.465
Fine aggregate	1.544	1.544	1.544
Coarse aggregate	2.946	2.791	2.636
Water	0.475	0.475	0.475

Table 4. For 100 x 100 x 500 beam, substitution of a portion of the coarse aggregate with plastic percentages.

Materials(kg)	Plastic waste replacement		
	5%	10%	15%
Cement	2.016	2.016	2.016
Plastic aggregate	0.362	0.724	1.086
Fine aggregate	3.602	3.602	3.602
Coarse aggregate	6.875	6.513	6.151
Water	1.109	1.109	1.109

Fig. 2. Crushed waste plastic mixed with cement, fine aggregate and coarse aggregate

Fig. 3. The cube specimens after 7- and 28-days curing.

RESULT AND DISCUSSION

The concept of substituting a portion of the coarse aggregate in concrete with waste plastic, like high-density polyethylene (HDPE), has garnered attention as a possible method for waste management and green building. This study was driven by the need to evaluate the use and performance of such plastic concrete before implementing it widely.

Fresh Concrete Properties: The slump test was conducted on freshly mixed concrete to determine the workability of the material. Concrete's workability is defined as how simple it is to mix, place, and compact. When plastic wastes are introduced as partial replacement of coarse aggregate in a concrete mix, the fresh properties of concrete could be significantly altered. Workability will vary depending on the precise plastic replacement percentage. In general, workability tends to decline as the ratio of plastic replacement rises. Figure 4 shows the results of the slump tests carried out. The outcome demonstrates that adding more plastic aggregate lowers the slump value even more when all other materials are constant. The particle size, shape, roughness, water-cement ratio, and quantity of cement, the amount of waste plastic aggregate added to concrete could increase or decrease the workability of the concrete. Due to its uneven shape, the fact that plastic and fine aggregate cannot mix, and the hydrophobic properties of plastic, plastic aggregate significantly increases the air content of concrete.

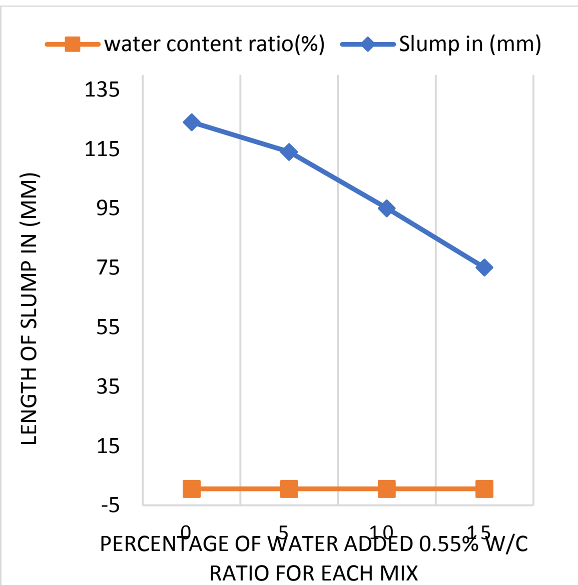

Fig. 4. The graphical representations of the slump values

Hardened Concrete Properties

Compressive strength: Concrete's compressive strength is a crucial mechanical characteristic that demonstrates its capacity to support loads. Studies have revealed that when the amount of plastic replacement rises, plastic concrete's compressive strength tends to decline. Comparing higher replacement percentages to standard concrete, reduced compressive strength is typically the outcome. However, variables including the type of plastic, particle size, curing circumstances, and mix proportions all affect how much strength is reduced. After a predetermined curing interval, the compressive strength of the manufactured concrete mix of grade M20 was evaluated. Fig. 5. Shows the result of compressive strength of both 7- and 28-days curing. The compressive strength varies from 35.66 to 17.88 N/mm2 for mixes ranging from 0% to 15%, respectively. The findings indicated that the percentage of plastic waste in the concrete mix increased with a decreasing trend in the compressive strength of the plastic cement. The concrete's compressive strength is determined by the density of its constituent materials; since plastic waste has a lower density than cement, the concrete with higher percentages of plastic waste has lower compressive strengths than the conventional mix. Concrete with 0% replacement has the highest compressive strength of 28 days curing which is 35.66 $N/mm^2$and 15% of 7 days curing recording the lowest strength of 17.88 N/mm^2. According to this experiment, when 15% of plastic waste is substituted for coarse aggregate in concrete at 28 days, the compressive strength of the concrete decreases by 26.08% when compared to normal concrete. As the amount of plastic aggregate increases, the development of compressive strength gradually decreases. Nevertheless, several investigations revealed an improvement in compressive strength for small amounts of plastic waste replacement.

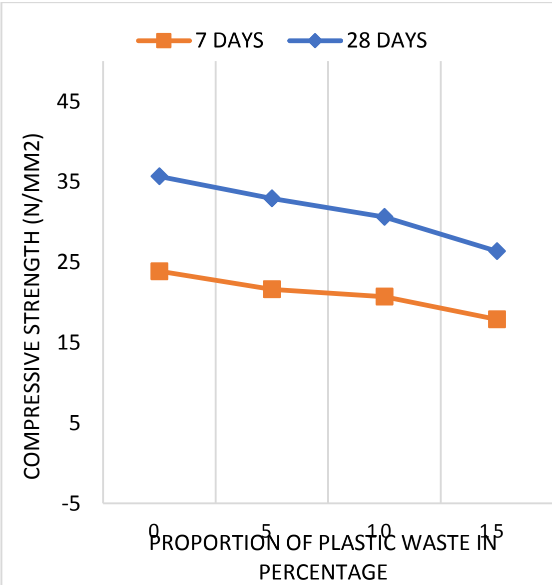

Fig. 5. The compressive strength of both 7- and 28-days curing.

Flexure Strength: Flexural strength is the capacity of concrete to withstand bending or cracking under strain. Growing percentages of plastic substitution have a detrimental effect on the flexural strength as well, citing study on plastic concrete. The aggregate and cement matrix may become less tightly connected as a result of plastic particles, reducing the flexural strength. Fig. 6. Showing the results of the flexure strength test of both 7- and 28-days curing beams. Testing values corresponding to replacements made from 0%, 5%, 10%, and 15% plastic waste. Up to 10% replacement, strength is practically comparable to standard mix concrete, however after that point, flexural strength rapidly decreases. According to the findings of this experiment, replacing 15% of the coarse aggregate with plastic waste reduces the flexure strength of concrete by 41.33% at 28 days when compared to standard concrete. It is possible to increase the flexural qualities of concrete by replacing a reasonable amount of coarse aggregate with plastic waste (less than 15% waste plastic waste).

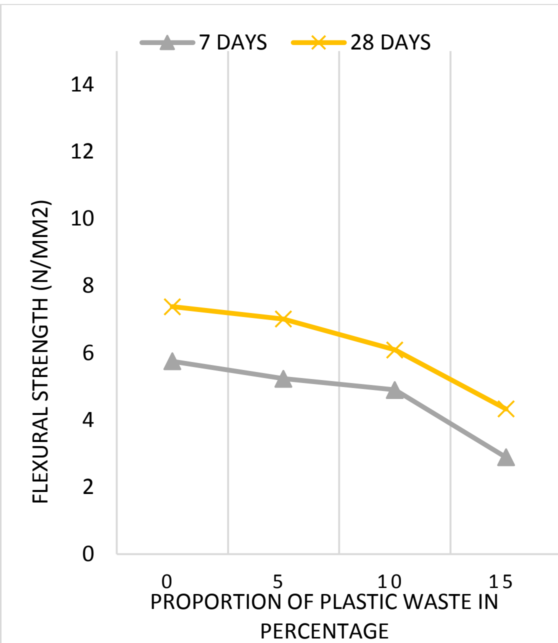

Fig. 6. The flexural strength of both 7- and 28-days curing.

Conclusion: There has been a lot of research done on using different forms of plastic waste as aggregate in concrete. The results showed that plastic waste might be utilised in place of natural aggregate in several applications. When the plastic concrete was compared to traditional concrete, it was discovered that the weights of the composite decreased as the amount of plastic replacement increased. Overall, it can be said that recycled plastic waste can be used in the construction of concrete up to a particular replacement level without affecting the material's mechanical qualities.

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