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# Experimental Analysis of HDPE Plastic Waste as a Partial Substitute for Coarse Aggregate in Concrete Performance

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***Abstract* - Hard plastic waste recycling and reuse is a good strategy that would minimize waste management issues and encourage the construction industry to use lightweight concrete. This paper examines the use of hard plastic waste and especially HDPE as a partial substitute of the natural coarse aggregate in M25 concrete. Plastic coarse aggregate (PCA) was added in the replacement proportions of 0, 5, 10, 15, and 20 percent and the concrete was tested with respect to workability and mechanical property, such as compressive, split tensile and flexural strength following the IS 10262:2019 guidelines. These findings show that concrete containing 10%PCA substitute is structurally performing at an acceptable level with slight changes in the strength, but beyond 10% replacement levels, compressive strength, tensile strength, and flexural strength are lost significantly. Reductions of 3.21 and 6.42 percent at 5 and 10 percent PCA respectively were realized, which enhances the manufacture of lightweight concrete. Despite a reduction in workability as the content of PCA increased, all mixes were still appropriate to general building. The paper singles out the prospect of plastic infused concrete as a eco-friendly construction product and a solution to the problem of plastic waste in Khairahani, Chitwan.**

***Keywords:*** M25 Mix design, Hard HDPE Waste Plastic, PCA, Workability, Admixtures.

## I. INTRODUCTION

### 1.1 Background

The rapid growth in plastic consumption has become one of the most significant environmental concerns worldwide. High-density polyethylene (HDPE), commonly used in bottles, containers, pipes, and packaging materials, constitutes a considerable portion of municipal solid waste due to its durability and non-biodegradable nature. Improper disposal of HDPE waste contributes to environmental pollution, landfill accumulation, and ecological degradation. Consequently, effective recycling and reuse strategies have become essential to achieve sustainable waste management and support circular economy principles.

Simultaneously, the construction industry is one of the largest consumers of natural resources, particularly coarse aggregates used in concrete production. Continuous extraction of natural aggregates has resulted in depletion of riverbeds, environmental imbalance, habitat destruction, and increased construction costs. Therefore, identifying suitable alternative materials that can partially replace conventional aggregates has become an important area of research in sustainable construction.

Concrete remains the most widely used construction material because of its high compressive strength, durability, and versatility. However, conventional concrete possesses high self-weight and requires significant quantities of natural aggregates. Incorporating recycled plastic waste into concrete provides a dual environmental benefit by reducing plastic disposal problems while conserving natural aggregate resources. Plastic aggregate also produces lightweight concrete with lower density, making it attractive for non-structural and semi-structural applications.

Among various plastic materials, HDPE exhibits excellent chemical resistance, low water absorption, high impact resistance, and durability, making it a potential candidate for aggregate replacement. Nevertheless, due to its smooth surface texture and hydrophobic characteristics, excessive replacement levels may reduce the bond strength between cement paste and aggregate, thereby affecting the mechanical properties of concrete. Therefore, determining the optimum replacement percentage is essential to achieve acceptable structural performance while maximizing environmental benefits.

Several researchers have investigated the use of recycled plastic waste in concrete with varying replacement levels. Most studies reported that partial replacement up to approximately 10–15% provides satisfactory mechanical properties while reducing concrete density. Beyond this level,

 

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significant reductions in compressive strength, tensile strength, and flexural strength are generally observed due to weak interfacial bonding and increased porosity.

The present study investigates the feasibility of utilizing HDPE plastic waste as a partial replacement for natural coarse aggregate in M25 grade concrete. Plastic coarse aggregate was incorporated at replacement levels of 0%, 5%, 10%, 15%, and 20%. The concrete specimens were evaluated for workability, compressive strength, split tensile strength, and flexural strength following IS 10262:2019. The study aims to determine the optimum replacement percentage that provides acceptable structural performance while contributing to sustainable waste management and environmentally friendly construction practices.

Concrete is ranked as the topmost man-made resource utilized in the construction industry worldwide. The global aggregate requirement for concrete production accounts for about 4.5 billion tons per year which alarms the necessity of finding alternative aggregate sources required for increasing trends of concrete production (Gunasekara, C., Setunge, S., Law, D.W., Willis, N., & Burt, T., 2018) Incorporating recycled plastic waste in concrete production is a sustainable approach for both disposing of plastic waste and aggregate scarcity, due to its economic and ecological advantages. Concrete composites replace various types of recycled plastics in the forms of aggregate, binder, filler or fiber reinforcement in different proportions where concrete properties are optimized (Saikia & de Brito, 2012). Polypropylene (PP), PET and HDPE are the most used plastics in the construction industry. However, the application and research studies on HDPE being used with concrete are very minimal compared with PP and PET.

The second material that is used more on earth than water is concrete, indicating that it is a very important material in the infrastructure in the world. The hydration process allows the material to be shaped into different shapes due to the composition of the material water, fine and coarse aggregates and binding material such as Portland cement. Nonetheless, its manufacturing process and extraction of the natural aggregates are major causes of environmental degradation, such as habitat disturbance, power use and release of greenhouse gases (Watts *et al.*, 2019). The use of HDPE plastic waste in the form of a partial substitution of coarse aggregate is a relevant step in the creation of sustainable construction in the modern concrete technology. The implications of HDPE in the concrete mix have been researched to understand the mechanical, light weight density, and environmental aspect of using HDPE in concrete mix, and it has been revealed that although HDPE leads to a reduction in the environmental impact of plastic disposal, it also affects the structural behavior of concrete. Compressive strength and the changes in the workability can be lower due to the hydrophobic characteristics and low density of HDPE particles particularly at high replacement levels. Nevertheless, it can be employed to make lightweight concrete and enhanced chemical resistance to attack, which makes plastics susceptible to long-lasting use when used in controlled ratios (Kumar *et al.*, 2023; Singh *et al.*, 2024; Sharma *et al.*, 2025). The process of plastics degradation is a chemical reaction, and due to the considerable durability, versatility, and flexibility of plastics, they can be used in non-structural activities and as more environmentally friendly building materials. They are however non-biodegradable and have a high risk of exposure to the environment and health problems due to poor disposal practices. The emergence of plastic waste particularly in the developed countries highlights the necessity to have sustainable management systems such as reuse in construction and civil engineering works (Jones *et al.*, 2025). Higher education curricula in construction and engineering must ensure that the current technological developments in the application of concrete are inculcated. This will make the students have a mentality that will be in line with technological advancement, making them ready to innovate the use of new technologies in the construction industry. The relevance of concrete as an element of modern construction methods cannot be underestimated as can be seen in its use in interior design and furniture (Feizbahr and Pourzanjani *et al.*, 2023).

One of the most rolled out wastes to the environment is plastic that has since impacted negatively on the wildlife, their habitats and people over the last few decades. This underlines the fact that it is time to reconsider the need to recycle and reuse plastics. In the current world, there exist over 30 kinds of primary plastics and over thousands of varieties of secondary plastics and they are made by integrating diverse combinations and proportions of primary plastics. There are also numerous aspects according to which plastics can be classified as it is depicted. Various plastics possess varying features in terms of mechanical properties, durability resistances and various applications in relation to their compositions and chemical structures. In the world, polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polyethylene terephthalate (PET) and polystyrene (PS) are the most widely manufactured and used plastics that constitute 69 percent of the world plastic consumption. Polypropylene (PP) and low-density polyethylene (LDPE) constitute 17-16 percent of all plastic production in the world with high-density polyethylene (HDPE) and polyphthalamide (PP&A) coming next. Moreover, additives in the production of plastic products also occupy a large portion of the world plastic production (Andersen, L., Wejdling, A., and Neidel, T. L. (2015). Lukkassen, D., & Meidell, A. (2003).

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HDPE is a synthetic polymer, which is thermoplastic and belongs to the Macro plastic of PE. PE polymer consists of never lasting hydrocarbon chains in which the carbon molecule is linked to two other carbon molecules and two hydrogen molecules. The HDPE polymer chain has few attached branches that lead to the crystallization of the molecular chains of the pack liner packaged together in a regular manner. Consequently, semi-crystalline HDPE polymers are substantially more dense, rigorous and ductile with a relatively high bending strength of 20 to 45 MPa because the polymer chains are regularly packed. The density of HDPE is also low (950 to 970) kg/m$^3$, its flexibility is greater and tensile strength is 20 to 32 MPa. Moreover, HDPE is a chemically inert compound (Geyer, R., Jambeck, J. and Law, K.L., 2017; Lukkassen, D. and Meidell, A., 2003), and the melting point is 130 C and ignition temperature is 487 C (Alauddin, M., Choudhury I., El Baradie, M. and Hashmi, M., 1995). It was also observed by authors that the differentiation of HDPE coarse aggregate size in the range of 1/2-3/4 inch has not been significant to the compressive strength (Lopez, N., Collado, E., Diacos, L. A., & Morente, H. D. (2018).

Kathmandu consumes between 4.7 to 4.8 million plastic bags in a day, out of which plastics constitute about 16 percent of the urban wastes that amount to about 2.7 tons of plastic wastes per day. The paper notes that worldwide, more than 9.1 billion metric tons of plastic were created during the past 1950-2018 of which most is still in the environment owing to the long degradation rate estimated at approximately 500 years per single plastic bag. The results of ICIMOD highlight environmental and health risks of improper management of plastic debris in Nepal, such as water, soil, and air pollution (Shrestha *et al.*, 2018). Kathmandu produces about 800 tons of non-biodegradable wastes on a daily basis, and about 4.7 to 4.8 million bags of plastic were consumed daily. In the landfills, up to seven types of plastics can be seen and the lowest grade of plastics can greatly decrease the lifespan of landfills. The percentage of plastic waste that can be recycled is only one-third because of the composition of the material. The mismanagement of plastic has caused pollution of water, land, and air that contributes to the climate crisis and renders the surrounding environment and health significant dangers. (Mishra *et al.*, 2018).The threat of the lack of innovative solutions to the global plastic waste crisis, such as using plastic waste in construction as an incomplete substitute of coarse aggregates in concrete. This would not only save the dependency on natural resources, but also lessen the environmental impact of uncontrolled plastic waste like waterways blockages, degraded scenery, and wildlife risks. (Seay *et al.*, 2022). The waste plastic of High-Density Polyethylene (HDPE) has a number of significant characteristics that render it useful in recycling and reusing it. It has a high strength to density ratio, and the average density is between 0.93 and 0.97 g/cm$^3$, meaning that it can possess high tensile strength and be lightweight (Vaishnavi *et al.*, 2024). The durability of HDPE is also discussed, and this material has excellent impact and abrasion resistance, which can be used in both structural and packaging. HDPE is chemically resistant to a large variety of substances such as acids, alkalis, oils, and solvents among others, which is why it finds wide application in containers and piping systems (Vaishnavi *et al.*, 2024). Also, it is not highly moist, which means that it does not lose its dimensions in wet conditions (Maunuvaara *et al.*, 2025). In the environment, HDPE can be recycled with high results as it can undergo reuse numerous times without making much loss on its mechanical characteristics. This is why recycled HDPE (HDPE) can be considered a sustainable material to be used in construction, consumer products, and packaging to reduce waste in landfills and help to conserve natural resources (WasteTrade *et al.*, 2025).

Khairahani Municipality in Chitwan addresses the plastic pollutions through partnerships along with organizations like Safaurja Nepal which is operates a plastic waste collection and processing facility featuring plastic recycling alongside composting and material recovery. Specific in daily collection figures from household and industrial plastic waste in tons per day data are does not available in surveys and remain still unavailable in any public reports, authors, researcher though nearby Chitwan khairahani areas generate notable plastic volumes amid broader waste challenges. Neighboring Bharatpur collects 25 tons of waste plastic monthly and about 0.83 tons waste plastic collect per daythis is done through Nepal Plastic Byabasayi Sangh and then sold to recyclers.indicating small-scale recovery typical in the region. [Source: Clean Energy Nepal & Environment and Public Health Organization. (2004, July). Solid waste management in Bharatpur municipality (Solid Waste Management in Nepalese Municipalities, No. 6)]. In case of Ratnanagar Municipality solid waste generation is 13.841 tons/day (Household: 6.776 tons, Institutional: 366 kg, Commercial: 6.699 tons) where plastic composition in different sectors are household waste: 20% plastics in urban wards, 80% plastics in rural wards, Institutional waste: 18.17% plastics & Commercial waste: 23% plastics. [Source: Solid Waste Management Baseline Study in Ratnanagar Municipality (SWMTSC, ADB, 2012), Table 12 and waste composition analysis]

The mayor of Khairahani Municipality has stated that waste management is a major problem due to the lack of a proper dumping site, with public land in Khairahani-5, Gaucharan used temporarily (Aryal, 2019). The municipality plans to process degradable waste into compost manure and biogas but seeks suitable infrastructure locations (Rising Nepal Daily, 2024). Local youth networks like the Amnesty

 

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International Khairahani Youth Network (AIKYN) conducted school campaigns on climate change and plastic pollution (Amnesty International Khairahani Youth Network, n.d). Studies show high plastic waste and microplastics in the Narayani River, impacting ecosystems near Bharatpur and Chitwan National Park (Kathmandu Post, 2025). Chitwan National Park became Nepal's first plastic-free zone in January 2019, banning plastic bags (WWF, 2019). A plastic recycling facility under Project CAP opened in Bharatpur in April 2025 (Himalayan Times, 2025). Safa Urja is a company that has been actively involved in solid waste management in Bharatpur, Khairahani, and Ratnanagar Municipalities in Chitwan, Nepal (Safa Urja, n.d.). Safa Urja collaborates with the municipalities to collect municipal waste from households and businesses in Bharatpur, Khairahani, and Ratnanagar, ensuring proper segregation of waste by separating organic waste suitable for composting from non-recyclable waste (CLARE Programme, 2025). The company also focuses on recycling and resource recovery from the municipal waste to minimize the amount of waste sent to landfills (Safa Urja, n.d).

As the most popular artificial resource, concrete is exposed to increasing sustainability issues, because of its tremendous aggregate demand and ecological effects, so recycled plastics, and especially HDPE, seems an effective solution. Although PP and PET have been more commonly researched, HDPE possesses benefits that are unique to it, including high durability, chemical resistance, recyclability, and lightweight, but it diminishes compressive strength and workability when overused. The regulated utilization of HDPE in the construction of concrete may lead to lightweight plastic composites that are environmentally friendly, and can be applied in non-structural purposes, which can resolve the issue of plastic waste and the shortage of aggregates at the same time. With the raised concerns on the danger of plastic pollution all over the world and locally, and in Kathmandu, the incorporation of HDPE waste into concrete is not only a way of curbing environmental risks, but also a way of promoting sustainable construction. That is why the introduction of HDPE recycling into concrete production is one of the essential steps towards decreasing the ecological degradation, preserving the natural resources, and developing the new technological aspects of construction.

### 1.2 Statement of the Problem

HDPE (High-Density Polyethylene) waste plastic aggregate concrete is a novel and ecological concrete material, which utilizes recycled HDPE plastics in part of the natural coarse aggregates. The method can aid in solving the increasing problem of plastic waste by recycling it into lightweight construction that is durable. Research has indicated that plastic can be utilized in concrete up to 20 percent of the replacement material that can increase the density of concrete, decrease the environmental impact of construction activities. The overall structural performance will be similar to conventional concrete despite a slight reduction in the workability of the mix, and it is therefore a promising solution to waste management. Home and industrial plastic waste are commonly disposed of in landfills, which cause severe environmental pollution and health risks. They underline the fact that these impacts need to be reduced through proper management which implies recycling and reuse to enhance the sustainability of the environment as well as health of the population. (Alabi *et al.*, 2021).

Toxic gases, including volatile organic compounds (VOCs) emitted by the melting waste of plastic household waste by heating to generate hard plastic can cause harm to human health and the environment. They encourage the use of other forms of processing at reduced temperatures to reduce toxic emissions and encourage safer recycling processes (Olson *et al.*, 2025). The use of plastic waste, especially hard plastic as a partial substitute of natural coarse aggregate in concrete, is not well explored. They research the mechanical performance of concrete mixes with M25 grade with different content of plastic waste. Results indicate that small percentages are strong but higher ratios will have more profound compressive and flexural strength implying the necessity of accurate mix design and more studies on sustainable applications (Mohamedsalih *et al.*, 2024).

The mismanagement of household and industrial plastic wastes in landfills is one of the causes of environmental degradation and health hazards. Although recycling of hard plastic is beneficial to the environment, it generates toxic gases due to the processing high temperature. To contain this, low temperature processes are suggested. Furthermore, the inclusion of shredded hard plastic waste into M25 grade concrete in ratios less than 10 percent can ensure the structural integrity, though the proportional incorporation of the mixes will have to be meticulously planned, ensuring the balance is made between strength and sustainability.

Khairahani Municipality faces acute waste management challenges, relying on temporary open dumping at Gaucharan on public land due to lacking proper infrastructure, while plastic pollution severely impacts nearby Narayani River ecosystems and Chitwan National Park. Despite promising initiatives like composting and biogas plans, youth-led awareness campaigns by AIKYN, the park's plastic ban, a new Bharatpur recycling facility, and Safa Urja's effective waste segregation and resource recovery, persistent gaps in dumping sites and processing capacity continue to exacerbate environmental degradation.

 

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One of the clever and environmentally friendly methods to decrease pollution and use natural resources is the utilization of recycled HDPE (High-Density Polyethylene) plastic waste in concrete. Concrete can remain strengthened and at the same time be made lightweight by substituting a maximum of 20 percent of natural coarse aggregates with HDPE. Nevertheless, when plastic melts down at high temperatures, it emits toxic gases, and therefore, when in safer circumstances, low temperature techniques should be followed. It has been established that very little plastic (less than 10 percent) can make concrete strong, but beyond that level (over 10 percent) it can become weak, and hence it should be cautious when designing the mix.

### 1.3 Research Questions

To achieve the objectives of the study, the following research questions would be used to get the answers to the following questions:

- How does the addition of Plastic Coarse Aggregate (PCA) affect the slump value workability of fresh concrete.
- How does Plastic Coarse Aggregate (PCA) affect the (compressive, split tensile and flexural strength) to form light weight of concrete.

### 1.4 Objectives

The main objective of the study is to determine how HDPE waste plastic affects the workability, compression, split tensile & flexural strength characteristics and density of the concrete. The specific objectives of the study are as follows.

- To evaluate the slump value workability test of fresh concrete varying percentage replacing with PCA (Plastic Coarse Aggregate).
- To assess the (compressive, split tensile and flexural strength) of concrete replacing with Plastic Coarse Aggregate (PCA) to form light weight of concrete.

### 1.5 Scope and Significance of the Study

Experimental analysis of natural aggregate and plastic aggregate in concrete study contributed to the discipline of civil engineering in a number of ways. The following were some of the important aspects that pinpointed the importance of this study:

The authors have demonstrated that the partial utilization of hard HDPE plastic waste as an alternative to natural coarse aggregates in the concrete can enhance such concrete properties as strength, water resistance, and lightweight density. It is ideal in lightweight structures such as Energy efficient structure, non-load bearing structure, building structure and floating platforms. The approach assists in reducing the waste plastic pollution, reduces construction expenses, and also promotes the enhanced recycling and reusing purpose and smarter waste management system.

Hard HDPE waste plastic as an aggregate in concrete will reduce the pollution generated and implement a circular economy through a reduction in landfill and riverbank waste. By substituting 5 percent to 20 percent of natural coarse aggregate with recycled waste plastic resources such as stone and gravel are conserved. This is ideal in lightweight structures that do not carry any load like partitions and prefab units. It also stimulates green projects such as eco-pavers and low traffic roads. In general, it stimulates lightweight cost-effective construction and enhances the development of green building materials.

### 1.6 Limitation of the Study

It was revealed that hard plastic waste when used in M25 grade of concrete can be effective to a certain extent of 10 percent replacement but it must have its limits. It has not tested any other concrete grade and has not considered other types of plastic as well as other materials and conditions of the real world such as weather and moisture. The experiments were carried out in a laboratory with local materials (Fine and coarse aggregate) in Khairahani, Chitwan and hence may not be the same elsewhere. Neither did it examine long-term effects or chemical reactions. Further investigation is required to ensure that this approach is safe and can be used scaled and in other settings by checking its performance over time.

- Other mechanical properties of concrete (such as compressive, tensile as well as flexural strength) tests were not done.
- The impact of different types of plastics, particularly mixed or contaminated waste was not researched thoroughly. Plastic mixture to be used in the production of HDPE waste plastic is assumed to remain constant.
- The absorption of the plastic water is assumed to be zero as a utilization of HDPE waste plastic.
- The total cost estimation is not stated during the process of manufacturing HDPE plastic.
- The used materials (fine aggregate, coarse aggregate and HDPE plastic) source from Khairahani Chitwan, that may cause variations in results.

## II. LITERATURE REVIEW

The utilization of plastic waste as aggregate in concrete has gained considerable attention due to increasing environmental concerns and the depletion of natural aggregate resources.

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Saikia and de Brito (2012) investigated the use of plastic waste as aggregate in cement mortar and concrete. Their review concluded that recycled plastic aggregate significantly reduces concrete density and improves thermal insulation, although excessive replacement decreases compressive strength because of weak bonding between plastic particles and cement paste.

Ismail and Al-Hashmi (2008) studied waste plastic as partial replacement of sand in concrete mixtures. Their experimental results indicated that low replacement percentages improved waste utilization without substantially affecting concrete strength, while higher replacement levels resulted in reduced mechanical performance.

Choi et al. (2005) evaluated lightweight concrete produced using recycled plastic aggregates. They observed that plastic aggregates considerably reduced concrete density, making the material suitable for lightweight construction, although compressive strength decreased with increasing plastic content.

Batayneh et al. (2007) examined the reuse of plastic waste in concrete mixtures and reported that replacement levels up to approximately 10% produced acceptable mechanical properties while offering environmental benefits through waste reduction.

Rai et al. (2012) investigated concrete containing recycled plastic waste as coarse aggregate. Their findings demonstrated that partial replacement improved sustainability and produced lightweight concrete, whereas replacement levels above 15% significantly reduced compressive and tensile strengths.

Bhogayata and Arora (2018) reported that incorporating recycled plastic aggregates enhanced impact resistance and ductility while reducing concrete density. However, they emphasized that the optimum replacement level should remain below 15% to maintain satisfactory structural performance.

Gu and Ozbakkaloglu (2016) reviewed recycled plastic in concrete and concluded that particle size, plastic type, replacement percentage, and surface treatment significantly influence concrete performance. They recommended further research on optimizing plastic aggregate properties to improve interfacial bonding.

Overall, previous studies consistently indicate that recycled HDPE plastic can be successfully utilized as a partial replacement for coarse aggregate in concrete. Most researchers recommend replacement levels between 5% and 10% for achieving a balance between mechanical performance, lightweight characteristics, and environmental sustainability.

Rapid urbanization and industrial development have certainly increased the numerical quantities of plastic wastes discarded across the world. Numerous studies have shown that non-biodegradable plastics which include HDPE remain in the environment for a very long time and this results in landfill overflow and degradation of ecology (Saikia & de Brito, 2012; Geyer *et al.*, 2017).

Plastics, and in particular, those with a high-density polyethylene (HDPE) are all around us in our packaging, food and construction, and our daily household items due to being tough and low cost. The issue is that they will not biodegrade, and so resulting in packed landfills, prolonged ecological impact, etc. One of the most significant issues presently, particularly in less-developed nations, is pointed out by a group of researchers who pose that dumping such plastic waste improperly is a big issue today and that the waste-management systems in developing countries are still so thin (Saikia & de Brito, 2012; Geyer *et al.*, 2017).

Recent works have strengthened the anxiety on the continued presence of plastic waste in the environment. It has been focused on the fact that non-biodegradable plastics end up in landfills and waterways in the long run threatening the ecological well-being. Land filling and incineration continue to be generally a dominant method of plastic waste management on a global scale, even though they have negative effects on the environment. Also it was previously indicated that plastics will never disappear in the ecosystems and pollute the soil and water resources, hence the need to create new methods of recycling plastics including using them as building materials. (Ling and Mo, 2000; Das, Alam, and Chowdhury, 2019; Edmund *et al.*, 2019)

Recycling and re-using plastic waste has been widely accepted as a sustainable solution to reduce pollution and at the same time ensure that our natural resources are controlled. In the construction industry the waste recycled plastic in concrete would work well since it addresses not only the accumulation of plastic waste but also shortage of natural aggregates. Previous research indicates that the construction industry consumes enormous amounts of coarse natural aggregates thus causing over-quarrying and environmental degradation (Ismail & Al-Hashmi, 2008; Siddique *et al.*, 2008). Uncontrolled extraction of aggregates from nature has obviously led to environmental degradation, which has resulted in exploration of some alternative materials to those, such as recycled plastic waste (Ismail & Al-Hashmi, 2008; Siddique *et al.*, 2008). Then by replacing some of those

 

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aggregates with recycled plastic, we can be pushed over to more sustainable construction methods.

A number of laboratory tests have been undertaken to test the possibility of utilizing recycled plastic waste as aggregate in concrete. According to these studies, with an appropriate treatment of the plastic into a coarse-aggregate-like form you may reduce the total density of the concrete resulting in a light mix that may be used in non-structural applications- and even structural elements in some cases (Choi *et al.*, 2005; Albano *et al.*, 2009). Moreover, recycling plastic in concrete is a sound solution to send it to landfills and minimize pollution, but still produce something that can be used in engineering.

Despite all that, there are concerns among the researchers regarding the fact that plastic concatenates with cement. The hydrophobic, smooth surface of plastic can also result in poor connections between the aggregate and cement paste thus weakening the strength of concrete (Frigione, 2010; Saikia and de Brito, 2014). This implies that a methodical search on various replacement levels will be required in determining an optimum balance between environmental benefits and an agreeable mechanical performance.

## III. RESEARCH METHODOLOGY

Even through more researcher and authors gives several studied about plastic aggregate partially replaced with natural coarse aggregate in terms of mixed waste plastic (like LDPE, PP, Recycled waste plastic) that leads to reduced density &improved sustainability with acceptable mechanical performance for normal conventional concrete at low replacement level. Most of the researcher conformed that at specially at lower to moderate replacement level ratio (5%-15%) to provides a balance between strength and weight reduction property of concrete which we have already discussed in above section.

In the sense of HDPE plastic type, only a few studies are seen in a recent year focusing on HDPE plastic aggregate as a partially replaced with coarse aggregate indicating that limited mechanical performance for normal conventional concrete were achieved at lower to moderate replacement level ratio (5%-20%) to provide a reasonable balance between concrete strength & lightweight property of concrete. In context of mechanical performance of concrete others researcher/authors are primarily works at higher mis design concrete M30 or above at lower to moderate replacement ratio. Now, following the same approaches the study adopts an M25 design mix & directly addresses the manufacturing process of HDPE plastic waste that focusing on improvement of HDPE plastic quality, surface treatment & performance when used as a replacement works.

The methodology for the completion of the research included experimental testing of the effect of HDPE waste plastic partially replacing or substituting natural coarse aggregate at varying percentage replacements. Firstly, different research articles, papers, and reports were studied to gain a deep understanding of the work and determine the way forward. Then, required related material were tested, concrete mix design procedure as per guideline to find out their ratio, specimens/samples were prepared and experimental tests on mechanical performance and physical characteristics were conducted. After the tests were performed, the experimental results were compared and validated.

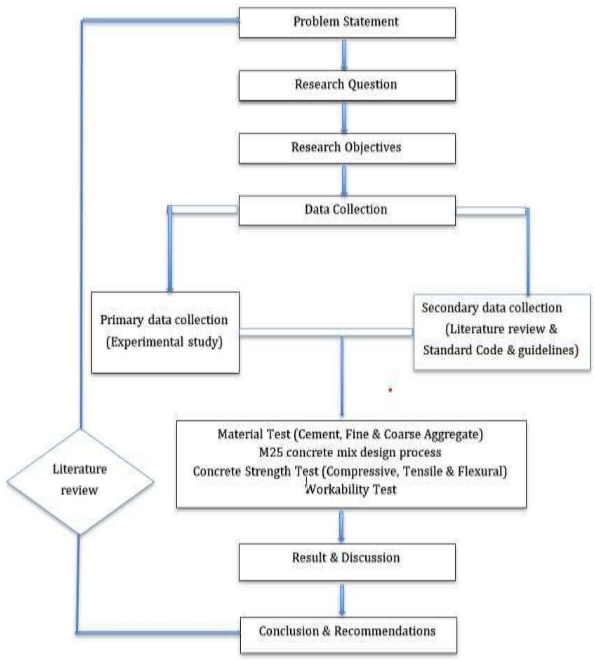


**Figure 1: Methodological diagram of research detailing**

### 3.1 Research Design

The study design applied in this study was the experimental design which aimed at assessing the impacts of adding HDPE waste plastic to the natural coarse aggregate as a substitute in different percentages. The objective of the study was to establish the influence of HDPE waste plastic on the workability of concrete, compressive strength, splitting tensile strength and splitting flexural strength of concrete. The study was carried out in a number of steps, namely, the selection of materials, the design of the concrete mix, the sample preparation, and laboratory testing.

### 3.2 Data Collection

The data collection section was divided into two parts: primary data collection and secondary data collection.

 

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### 3.2.1 Primary Data Collection

Experimental Study: The experimental research was carried out by using laboratory tests, which involved sample preparation and compression, splitting tensile and splitting flexural loading tests. The paper entailed a mix design prepared of M25 grade concrete, whereby the Natural Coarse Aggregate (NCA) was substituted by 5, 10, 15 and 20 percent of Plastic Coarse Aggregate (PCA) in the cube and the cylinders respectively. To measure the workability of fresh concrete, tests were conducted to measure compressive strength, tensile strength, flexural strength and slump value.

### 3.2.2 Secondary data collection

Literature review: The use of HDPE waste plastic as a substitution of natural coarse aggregate was conducted in a comprehensive literature review of the existing literature to establish the relevant experimental research. This was done through the search of academic databases as well as the examination of journals, conference proceedings, and books. The review was useful in determining best practices and challenges in carrying out such studies as well as gives some insights on possible discrepancies in experimental results.


Note: All these pictures were taken by myself and source from Safa Urja Pvt. Ltd (khairahani Municipality ward no -4, Chitwan)

**Figure 2: Process of preparation of HDPE plastic in Industry**

Standards and guidelines: Relevant standards and guidelines on the utilisation of varying percentage substitution of Natural Coarse Aggregate (NCA) by Plastic Coarse Aggregate (PCA) were studied. This was a source of great knowledge concerning the suggested processes and methods of conducting experimental research related to such substitutes. The mentioned standards were NS 572:2076 on cement testing, IS 10262:2019 on concrete mix proportioning, and IS 383: 2016 on coarse and fine aggregate.

**Table 1: Physical properties of admixtures**

| TRUBUILD CPS111: Key Properties & Functions | |
|---|---|
| Type | Silicate-based waterproofing compound |
| Appearance | Brown-red liquid |
| Specific Gravity | 1.03-1.07 |
| Chloride Content | Max 2% (IS: 2645:2003 compliant) |
| pH Range | 9-13 |
| Dosage | 200 ml per 50 kg bag of cement |
| Air Entrainment | Not specifically designed for air entrainment |
| Function | Reduces permeability, enhances cohesion, improves workability |
| Shelf Life | 24 months (stored between 2-40°C) |
| Application Areas | Roof slabs, bathrooms, basements, water tanks, drains, etc. |

## 3.3 Strength Test on Concrete

### 3.3.1 Compressive Strength Test

Measuring the compressive strength of concrete was done in accordance with standard procedures. Each cube specimen was measured in terms of the dimensions as close to 0.2 mm as possible and weighed before testing. The bearing surfaces of Compression Testing Machine (CTM) were wiped clean and any debris of the contact surface of the specimen was swept away. The cube was made to rest each side of the load on the cast and not upon the top or bottom. The axis of the specimen was perpendicular to the center of the thrust of the platen in a spherically seated position. It did not include a packing material between the plates of steel and the specimen. Contact was made with the spherically seated block with the movable part being lightly rotated by hand as the block was seated uniformly. The applied load was then ramped slowly and progressively at a rate of about 140 kg/cm2/minute to the specimen till the specimen could not sustain the applied load. The load maximum was recorded & a note was made on the appearance of the concrete at any strange failure mode.

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#### 3.3.2 Sample preparation and Procedure for Casting Concrete Cubes

This research dealt with 30 cube specimens of concrete that was prepared based on M25 design mix. Introduction of HDPE waste plastic was a partial replacement of coarse aggregate at five levels namely 0, 5, 10, 15 and 20. To determine the early-age compressive strength, each three specimens were tested at both 7 and 28 days of curing with each replacement percentage. All cubes were poured in regular molds of 150 mm x 150 mm x 150 mm and allowed to dry at room temperature in water. A Compression Testing Machine (CTM) was used to determine the compressive strength, which was done in accordance with the relevant standards. This sampling technique yielded credible information to measure the effect of the HDPE content on the strength development of concrete with time.Prior to casting, all cube molds were washed and also lightly oiled with form oil and none was left behind. Bolts and nuts were well-fixed to remove the loopholes between the base and side plates. The mold was positioned on a clean and smooth surface which was hard. Concrete was gathered on three randomly chosen batches depending on the M25 mix design and placed in the mold in layers not more than 50 mm in thickness. A steel float was used to smooth the top surface and scrap off any extra concrete. The mold was left to set after 24 hours. Within 90 minutes, a marking on the top surface was done with the number of the specimen and the date of casting. After the first curing time was over, it demolded the cube and completely immersed it in a clean water tank. The specimens were sent to the laboratory after 7 and 28 days of curing to test the compressive strength of the test samples. After the complete action the whole process was repeated at each replacement percentage of (5%, 10%, 15%, & 20%)PCA level then finally note down the each replacement level strength test value.

#### 3.3.3 Splitting Tensile Strength Test

The tensile strength of concrete was determined in the form of the splitting tensile strength according to IS: 5816:1999 by an indirect method. Cylindrical samples that are 300 mm long and less. The platens of a Compression Testing Machine were placed horizontally with 150 mm in diameter. A compressive load that acted equally on the vertical diameter of all the cylinders was imposed. Since the Poisson effect, the loading applied created horizontal tensile stresses which made the specimen tear vertically into two. The compressive stress was high in the region just under the loading points but most parts of the cylinder were exposed to lateral tensile stress. It was supposed that one-sixth of the depth was compressed, and the rest of the 5/6 was in tension. In case the concrete were elastic, failure ensued because of smooth lateral tensile stress in the vertical plane. The tensile strength was calculated by adopting the following formula: ft = / Where: P = Load at failure, D = Diameter of the cylinder and L = Length of the cylinder.

#### 3.3.4 Sample preparation and Procedure for Casting Concrete cylinder

The test program consisted of 15 cylindrical specimens casted using M25 grade concrete mix. Natural coarse aggregate was substituted with quarry dust at five levels of 0, 5, 10, 15 and 20 percent. There were 3 specimen tests on 7 days and 28 days of curing to guarantee consistency and reliability, varying the replacement percent. All cylinders cast were of standard molds of 150 mm diameter and 300 mm height in accordance with IS: 5816-1999. The specimens were cast and allowed to cure at room temperature in water. Split tensile strength was analyzed where a compression testing machine was used to apply the diametral load till failure. The tensile strength of each mix ratio was determined using the normal formula, and the mean of each and standard deviations were taken to determine the performance at early age. Before casting, the moulds were emptied of all traces of oil and grease and then they were covered by a coating of thin form oil so there was not a drop of it left outside. Bolts and nuts were tightened by all means in order to exclude any gaps. The mold was put on a smooth, flat, and firm surface. Three batches of concrete were randomly taken, and placed in the mold in layers of not more than 50 mm thick. The surface of the top was evened with the help of a steel float and all surplus material surrounding the mold exceeded. The mold was left to dry in 24 hours to enable first settling. The marking of the specimen number and the date of casting was done on the top side after 90 minutes. After the initial period of the curing was effective, the specimen was demolded and then completely immersed in a clean water tank. The specimens were taken to the laboratory after 28 days of curing. At least 3 specimens were made under each mix ratio and average test results were taken to decide the tensile strength of concrete. After the complete action the whole process was repeated at each replacement percentage of (5%, 10%, 15%, & 20%) PCA level then finally note down the each replacement level strength test value.

#### 3.3.5 Flexural Strength Test

The flexural strength test is one of the most important mechanical tests used to evaluate the bending performance of concrete. Unlike compressive strength, which measures the concrete's ability to withstand axial compressive loads, the flexural strength test determines the concrete's resistance to bending stresses and tensile forces developed at the bottom of structural members such as beams, slabs, pavements, bridge decks, and industrial floors. In reinforced concrete structures,

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flexural strength is a critical design parameter because many structural elements primarily experience bending under service loads. Therefore, evaluating the flexural performance of concrete containing recycled High-Density Polyethylene (HDPE) plastic coarse aggregate is essential to determine its suitability for structural and semi-structural applications.

In this study, the flexural strength of M25 grade concrete was determined in accordance with IS 516:2018 (Methods of Tests for Strength of Concrete). Beam specimens measuring 100 mm × 100 mm × 500 mm were cast using five different replacement levels of HDPE plastic coarse aggregate, namely 0%, 5%, 10%, 15%, and 20% by weight of natural coarse aggregate. After casting, all beam specimens were allowed to set for 24 hours before being demoulded and cured in clean water for 28 days under standard laboratory conditions. Proper curing ensured adequate hydration of cement and minimized variations in strength development among the different concrete mixtures.

The flexural strength test was conducted using a calibrated Universal Testing Machine (UTM) equipped with a flexural loading arrangement. Each beam specimen was positioned on two supporting rollers while the load was applied through two loading rollers placed symmetrically at one-third of the span length, following the two-point loading method recommended by IS 516. During testing, the load was applied gradually and continuously without any sudden impact until the specimen failed due to crack propagation. The maximum load carried by each beam before failure was recorded, and the flexural strength was calculated using the standard formula prescribed in the code. For each replacement level, three beam specimens were tested, and the average flexural strength was considered for analysis to improve the reliability and consistency of the experimental results.

The incorporation of HDPE plastic aggregate significantly influenced the flexural behavior of concrete. Conventional concrete prepared with natural coarse aggregate exhibited the highest flexural strength because of the strong interfacial bond between the cement paste and natural aggregate particles. When HDPE plastic aggregate was introduced as a partial replacement, a slight reduction in flexural strength was observed at 5% and 10% replacement levels. However, the reduction remained within acceptable engineering limits, indicating that these mixtures retained sufficient bending resistance for several practical construction applications. The relatively small decrease in strength at lower replacement percentages suggests that a limited amount of HDPE aggregate does not severely affect the internal load-transfer mechanism of the concrete.

As the HDPE replacement level increased to 15% and 20%, a noticeable reduction in flexural strength was observed. The reduction can be attributed to several factors, including the lower stiffness and elastic modulus of HDPE compared to natural stone aggregate, the smooth and hydrophobic surface characteristics of plastic particles, and weaker adhesion between the plastic aggregate and the cementitious matrix. These factors reduce the ability of the concrete to resist tensile stresses developed during bending, leading to earlier crack initiation and faster crack propagation. Furthermore, the increased plastic content results in higher void formation and weaker interfacial transition zones (ITZ), thereby reducing the overall structural integrity of the concrete under flexural loading.

Despite the reduction in flexural strength at higher replacement levels, the concrete mixtures containing 5% and 10% HDPE aggregate demonstrated satisfactory performance for many non-critical structural and lightweight construction applications. The lower density of HDPE particles also contributed to the production of lightweight concrete, which offers advantages such as reduced dead load, easier transportation, improved thermal insulation, and enhanced sustainability. Therefore, the use of HDPE plastic aggregate provides an effective solution for recycling plastic waste while simultaneously conserving natural aggregate resources.

The experimental observations indicate that the optimum replacement level of HDPE plastic coarse aggregate is approximately 10%, where the concrete exhibits an acceptable balance between flexural strength, workability, weight reduction, and environmental sustainability. Beyond this replacement percentage, the decrease in flexural performance becomes significant, limiting its use in structural elements subjected to high bending stresses. Consequently, HDPE plastic aggregate can be recommended for lightweight concrete, pavements, footpaths, partition walls, precast blocks, and other applications where moderate flexural strength is sufficient while promoting environmentally responsible construction practices.

### *3.3.6 Flexural Strength Test Presentation*

The flexural strength test results demonstrate that the replacement of natural coarse aggregate with recycled HDPE plastic aggregate has a direct influence on the bending performance of M25 concrete. Figure X illustrates the variation in flexural strength for different HDPE replacement percentages after 28 days of curing. The control concrete (0% HDPE) exhibited the highest flexural strength due to the superior mechanical properties and strong bonding characteristics of natural coarse aggregates. As the percentage of HDPE aggregate increased, the flexural strength gradually

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decreased because the plastic particles possess lower rigidity and weaker bonding with the cement matrix. The concrete containing 5% HDPE aggregate showed only a marginal reduction in flexural strength compared with the conventional mix, indicating that a small quantity of recycled plastic can be incorporated without significantly affecting the structural performance. At 10% replacement, the reduction remained moderate, and the concrete continued to satisfy the strength requirements for many practical construction applications. This result confirms that moderate incorporation of HDPE plastic aggregate can successfully produce environmentally friendly lightweight concrete while maintaining satisfactory mechanical performance.

However, the specimens containing 15% and 20% HDPE aggregate exhibited a considerable decrease in flexural strength. The reduction is primarily associated with the poor adhesion between the plastic particles and hydrated cement paste, increased internal voids, and reduced aggregate stiffness. During testing, these specimens developed cracks at lower load levels, and crack propagation occurred more rapidly than in conventional concrete. The failure pattern also indicated that plastic aggregates tend to debond from the surrounding cement matrix before complete fracture, reducing the overall load-carrying capacity of the beam specimens.

The overall experimental results suggest that replacing natural coarse aggregate with up to 10% HDPE plastic waste provides an effective compromise between mechanical performance and environmental sustainability. This replacement level minimizes plastic waste disposal, conserves natural aggregate resources, and produces lightweight concrete with adequate flexural strength for several structural and non-structural applications. Therefore, the use of recycled HDPE aggregate represents a promising sustainable construction material capable of contributing to waste management and green building practices without causing significant deterioration in flexural performance.

## IV. RESULT AND DISCUSSION

The experimental investigation evaluated the influence of HDPE plastic coarse aggregate on the fresh and hardened properties of M25 concrete.

*Workability:* The slump value gradually decreased as the percentage of HDPE increased. The smooth surface texture and lightweight nature of HDPE particles reduced cohesion within the concrete mix, leading to lower workability. Nevertheless, all concrete mixtures exhibited acceptable workability suitable for normal construction practices.

*Compressive Strength:* Conventional concrete exhibited the highest compressive strength after 28 days of curing. Replacement of natural coarse aggregate with 5% and 10% HDPE resulted in only marginal reductions in compressive strength of approximately 3.21% and 6.42%, respectively. These reductions remained within acceptable engineering limits for several structural and non-structural applications.

However, replacement levels of 15% and 20% caused substantial strength reductions due to weak adhesion between the plastic aggregate and cement matrix, increased void formation, and lower stiffness of HDPE particles.

*Split Tensile Strength:* A similar trend was observed for split tensile strength. The 5% and 10% replacement mixtures maintained satisfactory tensile performance, while higher replacement percentages produced noticeable reductions owing to poor interfacial bonding.

*Flexural Strength:* Flexural strength decreased progressively with increasing HDPE content. The reduction became more pronounced beyond the 10% replacement level because plastic particles possess lower elastic modulus compared to natural aggregates.

*Density:* The density of concrete decreased with increasing HDPE replacement due to the lower specific gravity of plastic compared to natural aggregates. This characteristic demonstrates the potential application of HDPE concrete in lightweight construction.

*Overall Performance:* Among all mixtures, 10% HDPE replacement provided the best balance between mechanical strength, workability, reduced density, and environmental sustainability. Therefore, this replacement percentage can be considered the optimum level for producing eco-friendly lightweight concrete.

### 4.1 Tests on Cement

Cement is also an essential ingredient of concrete. Cement is prepared by crushing raw materials, mixing them in certain proportions and burning them in a kiln at a temperature of between 1300 deg C and 1500 deg C. A number of tests are performed in order to determine the various cement qualities. The following experiments were carried out:

#### *4.1.1 Standard Consistency*

Standard consistency test of cement results the following observation as shown in table. Observation and calculations

As per the observations of the standard consistency test of cement, it was desired to determine how much water was required to form a paste that would allow the Vicat plunger to enter 5-7 mm below the bottom of the mould as per IS 4031 Part 4:1988.

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### 4.2 Initial Setting Time

Initial setting time of cement results in the following data as shown in Table.

**Table 2: Initial setting time observation**

| Initial Setting Time of Cement (IS 4031-Part 5-1988) & NS 572:2076 | | | |
|---|---|---|---|
| cement | Percentage of water added | Time (min) | Penetration [from bottom (mm)] |
| 400 gm | 0.85*consistency of cement *weight of cement | 30 | 0 |
| | | 35 | 0 |
| | | 40 | 0 |
| | | 45 | 0 |
| | | 50 | 0 |
| | | 55 | 0 |
| | | 60 | 0 |
| | | 65 | 0 |
| | | 70 | 2 |
| | | 75 | 2 |
| | | 80 | 3 |
| | | 85 | 5 |

According to the first setting time test that was performed as per IS 4031-Part 5:1988, the aim was to find out the time when cement paste starts to lose its plasticity and begin to set. In this test, 400 grams of cement was combined with an equivalent of water of 0.85 of the standard consistency which makes the paste suitable in determination of setting time.

Penetration was measured at regular intervals using a Vicat needle. Between 30 and 65 minutes, the needle was fully penetrated (0 mm at the bottom) which meant that the paste was still plastic. After 70 and 75 minutes, the penetration decreased to 2 mm and this indicated that the paste had begun to stiffen. At 80 minutes the penetration of the needle was only 3 mm and at 85 minutes the penetration was 5 mm below the bottom indicating the starting point of setting of the cement hence the initial setting time of the cement was 85 minutes and the needle penetration was 5 mm below the bottom of the mould. The value is significant in the calculation of the workable time of cement in construction works. The surface of the top was evened with the help of a steel float and all surplus material surrounding the mold exceeded.

### 4.3 Final Setting Time

Final Setting Time of Cement (IS 4031-Part 5-1988) & NS 572:2076

According to the end setting time test performed as per the IS 4031-Part 5:1988, the objective was to find out the time when the cement paste becomes entirely deprived of its plasticity and becomes firm enough to be able to resist penetration. This is whereby the cement has completely hardened and is also available to load bearing uses.

**Table 3: Final setting time observation**

| Time After Mixing (min) | Needle Impression | Collar Impression | Observation |
|---|---|---|---|
| 30 | Yes | Yes | Not set |
| 60 | Yes | Yes | Not set |
| 90 | Yes | Yes | Not set |
| 120 | Yes | Yes | Not set |
| 150 | Yes | Yes | Not set |
| 180 | Yes | No | Final Setting Time |
| Final Setting Time = $T_3 - T_1$ = 180 minutes | | | |

During this test the impressions were tested at periodic intervals with the help of the Vicat apparatus. The needle impression and collar impression were all seen at 30, 60, 90, 120, and 150 minutes which meant that the cement was still in the setting process. The needle impression however at a 180 minutes existed and collar impression was missing; this indicates the final setting of the paste was complete enough to resist the collar. The cement should, therefore, be taken as hard after 180 minutes. This value is important in planning to have construction activities so that the cement may have time to settle before any additional actions or loading.

### 4.4 Mix Design and Mix Proportioning

Comparing weight difference and percentage reduction between Natural Coarse Aggregate (NCA) and Plastic Coarse Aggregate (PCA in the mixes of M25 mixes) the replacement of NCA with PCA leads to the regular and significant weight reduction of the aggregate, resulting in the mixes becoming increasingly light. The weight difference between the control mix (0% PCA) and introduction of PCA at 5, 10, 15, and 20 percent is 1149.76 and 1092.271034.7912.84 respectively, and the introduction of PCA results in a reduction of the weight difference of 3.21, 6.42, 9.63, and 12.84 percent. Split tensile strength was analyzed where a compression testing machine was used to apply the diametral load till failure. The tensile strength of each mix ratio was determined using the normal formula, and the mean of each and standard deviations were taken to determine the performance at early age. Before casting, the moulds were emptied of all traces of oil and grease and then they were covered by a coating of thin form oil so there was not a drop of it left outside.

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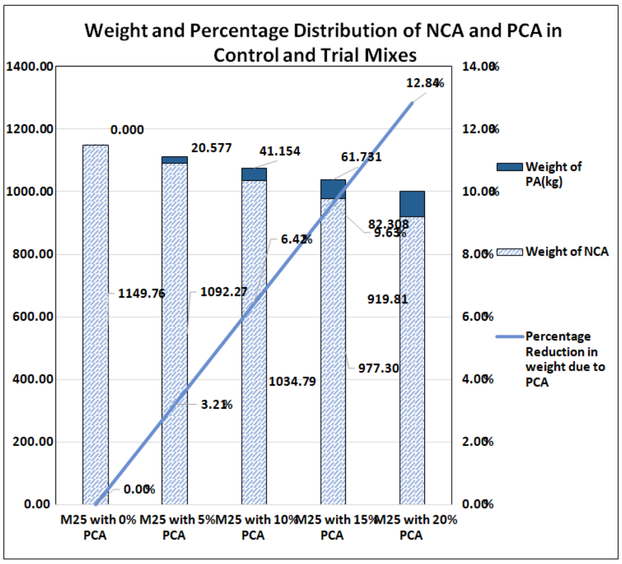


**Figure 3: Weight and Percentage Distribution of NCA and PCA in Control and Trial Mixes**

The outcome proves that the lightweight nature of concrete can be substantially enhanced by the percentage of PCA in the mix, therefore, proving the efficacy of PCA to be used to make lighter structural components without affecting the usual proportions of cement, fine aggregate, water, and admixtures.

### 4.5 Compressive Strength Test

28-Day Compressive Strength Test Result:

The statistical analysis was done by finding mean and standard deviation from calculated 28-day Compressive strength samples of M25 with 0% PCA, 5% PCA, 10% PCA, 15% PCA and 20% PCA samples respectively; it was used to assess the reliability of results. The obtained low standard deviation suggested that the data points are closely clustered around the mean, indicating a higher degree of consistency.

The 28 days compressive strength test of the M25 grade concrete with a different proportion of Plastic Coarse Aggregate (PCA) replacement shows uniform behavior on the mechanical performance. The control mix of 0% PCA had the largest average strength of 31.75 Mpa with a very low standard deviation of 0.05 Mpa which implies very consistent results. With increase in PCA content, compressive strength began to reduce gradually. Blends with 5% PCA at 10% PCA at 15% and 20% with the mixes having the 31.61 MPa, 31.24 MPa, 30.17 MPa and 30.06 MPa respectively. With this drop, most mixes had fairly small standard deviations implying dependable and consistent data amongst samples. Interestingly, the mixture with 15% PCA had the largest variability with a standard deviation of 0.30 MPa indicating less homogenous behavior of its samples. By contrast, the 20% PCA mix with the lowest strength demonstrates the lowest standard deviation of only 0.09 MPa, which is a sign of consistent performance in spite of decreased strength.

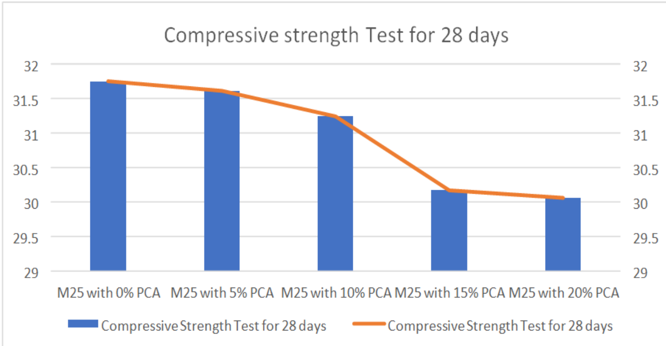


**Figure 4: 28-Day compressive strength test graph for different replacement of PCA**

The reliability of the results is supported by the statistical analysis that is based on mean and standard deviation. The standard deviation was between 0.375 MPa and 0.693 MPa, whereby the 5% PCA mix had the most variation which could have been as a result of imbalanced plastic particles. On the other hand, the standard deviations of mixes with 15% and 20% PCA had the lowest values, which mean that they were more consistent in their behavior even though their strength values were lower.

### 4.6 Split Tensile Strength Test

28-Day Split Tensile Strength Test Result:

**Table 4: 28-Days split tensile strength observation**

| Mix Designation | Split Tensile Strength Test For 28 day Sample (Mpa) | | | Statistical Analysis of Split Tensile Strength | |
|---|---|---|---|---|---|
| | Sample 1 | Sample 2 | Sample 3 | Mean strength (Mpa) | Standard Deviation |
| M25 with 0% PCA | 4.38 | 4.39 | 4.44 | 4.40 | 0.030 |
| M25 with 5% PCA | 4.07 | 4.08 | 4.11 | 4.09 | 0.020 |
| M25 with 10% PCA | 4.25 | 4.27 | 4.31 | 4.28 | 0.030 |
| M25 with 15% PCA | 3.36 | 3.37 | 3.4 | 3.38 | 0.020 |
| M25 with 20% PCA | 2.97 | 2.99 | 3.01 | 2.99 | 0.020 |

The statistical analysis was done by finding mean and standard deviation from calculated 28 day Compressive strength samples of M25 with 0% PCA, 5% PCA, 10% PCA, 15% PCA and 20% PCA samples respectively; it was used to assess the reliability of results. The obtained low standard deviation suggested that the data points are closely clustered around the mean, indicating a higher degree of consistency.

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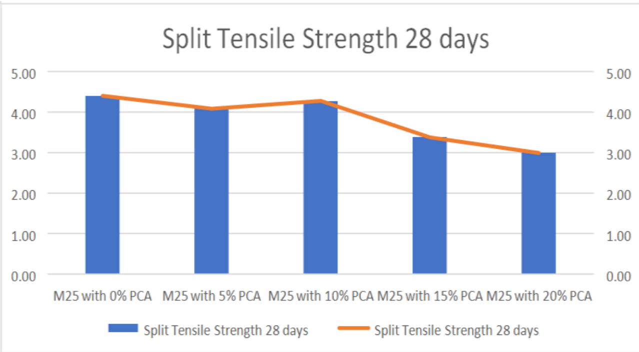


**Figure 5: 28-day split tensile strength test graph for different replacement of PCA**

The tensile strength test of M25 concrete on 28 days split tensile behavior of concrete with different contents of Plastic Coarse Aggregate (PCA) replacement shows that there is a clear pattern of mechanical behavior. A control mix with 0% PCA gave the highest mean tensile strength of 4.40 MPa that will be used as a reference point in assessing the effect of plastic aggregate inclusion.Tensile strength was generally decreasing as the content of PCA increased. The 5% PCA mix was slightly weaker with a strength of 4.09 MPa whereas the 10% PCA mix somewhat surprisingly rebounded slightly to a strength of 4.28 MPa indicating that a small amount of PCA use does not have a major deleterious effect on tensile performance and it can actually have some marginal benefits in some cases.

At higher rates than that 10 percent mark, though, the strength fell at a more pronounced rate. The 15% PCA mix gave a mean strength of 3.38 Mpa and the 20 percent mix dropped to 2.99 Mpa. This negative change means that increased amounts of plastic aggregate replacement damage tensile properties of concrete, probably owing to the deficiency of bonding efficiency and mechanical interlock of plastic particles as compared to the natural aggregates. There was a variation in the strength, but the standard deviation values of all mixes were low between 0.02 and 0.03 Mpa indicating uniform and valid results in each group. This close clustering of the mean enhances the plausibility of the experimental information and gives evidence that the mixing and testing processes were controlled.

### 4.7 Intersection Point (Balance of Strength)

The normalized strength analysis through the min-max method is important in revealing the behavior of compressive and split tensile strengths of M25 concrete to the increasing rates of plastic coarse aggregate (PCA) replacement. The graphical representation shows that there are two different curves one being the normalized compressive strength and the other normalized tensile strength at five percentages of replacement. At 0% PCA, the two values of strength are at the highest (normalized to 1.000), which forms the control mix and structural benchmark.

**Table 5: 28-Days splitting tensile strength and 28 days compressive strength data**

| Mix Designation | 28-Days Splitting tensile strength (MPa) | 28-Days Compressive Strength (MPa) |
|---|---|---|
| M25 with 0% PCA | 4.40 | 31.75 |
| M25 with 5% PCA | 4.09 | 31.62 |
| M25 with 10% PCA | 4.28 | 31.24 |
| M25 with 15% PCA | 3.38 | 30.17 |
| M25 with 20% PCA | 2.99 | 30.06 |

When normalizing both 28 days and Tensile strengths to 100%, we get the following table.

**Table 6: Normalization table (min-max method)**

| % Replacement | Compressive (MPa) | Norm. Compressive | Tensile (MPa) | Norm. Tensile |
|---|---|---|---|---|
| 0% | 31.75 | 1.000 | 4.400 | 1.000 |
| 5% | 31.61 | 0.955 | 4.090 | 0.831 |
| 10% | 31.24 | 0.832 | 4.280 | 0.900 |
| 15% | 30.17 | 0.472 | 3.380 | 0.472 |
| 20% | 30.06 | 0.434 | 2.990 | 0.345 |


**Figure 6: Balance of strength curve**

The strengths decrease with increase of the PCA content though unevenly. One interesting observation is made at 15 percent PCA as both normalized values coincide again at 0.472. This cross-sectional point depicts a second balance point of compressive and tensile performance, whereby the overall strength is minimized but the relative strength of the two categories of strength is maintained.

This two-intersection at 0% and a second time at 15% provides two important insights. First, the 0% PCA mix is obviously the best structural baseline, which provides the best performance with no compromise. Secondly, the 15% PCA mix, although it has lower values of strength, has a proportional relationship between compressive and tensile properties. This might prove useful in situations where equal

 

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degradation is not an issue and where sustainability concerns might indicate a trade-off in strength. Conversely, the blends containing 5, 10 and 20 percent PCA exhibit their divergence between the two types of strength, where tensile strength decreases faster than compressive strength. This pattern indicates that tensile performance is more sensitive to PCA addition as well as indicates that care should be taken when above 10 percent replacement is done, particularly in structural components where tensile capacity is crucial.

According to the normalized strength analysis, there are two points of equilibrium in M25 concrete with PCA replacement at 0% and 15%. The 0% PCA mix has maximum performance in compressive and tensile strengths hence it is the best structural base. The 15 percent PCA mix however tells a different story as the normalized compressive and tensile strength is equal even though the values of strength are low. This ratio can be beneficial in certain structural scenarios where the homogeneous cut in the strength is agreeable and eco-friendliness is of utmost importance.

However, the data also show that the tensile strength decreases more shortly than compressive strength above 15% PCA replacement. Such an imbalance may lead to the loss of the concrete stability and cracking resistance, particularly in tension-sensitive cases. As such, although 15 percent PCA is the maximum percentage of balanced structural integrity, 10 percent PCA mix is the best compromise. It provides a good compromise of sustainability with mechanical capability since it retains high strength with the use of recycled materials. This predisposes 10% PCA to make it a viable and effective option when it comes to building environmentally friendly buildings without compromising structural integrity.

This analysis has confirmed that 0percent and 15percent PCA replacement levels in M25 concrete are strength equilibrium points, compressive and tensile strengths are proportionate to each other. Although 0% PCA has the best performance, 15% PCA has an equal reduction in both types of strength making it structurally consistent even though it has lower values. Nevertheless, 10 percent PCA is the most feasible solution that does not sacrifice the strength too much but helps maintain sustainability by using partial plastic aggregates. In the previous result showed there are many types of plastic waste (other than HDPE) like (LDPE, PP, PET & Recycled plastic waste) that lead to reduced in density & improve sustainability with acceptable mechanical characteristics for conventional concrete at replacement level (5-15)% provide a limited strength and reduced weight but few studies are seen in a recent year focusing on HDPE plastic aggregate partially replaced with coarse aggregate indicating that limited mechanical performance achieved higher design mix M30 or above at replacement level (5%-20%) to provide balance between strength test (compressive upto 10% & tensile/flexural up to 15%) and lightweight property of concrete. Following these approaches the study adopts an M25 design mix & directly addresses the manufacturing process of HDPE plastic waste that focusing on improvement of HDPE plastic quality, surface treatment & performance when used as a replacement works.

### 4.8 Flexural Strength Test

28-Day Flexural Strength Test Result

**Table 7: 28-Days flexural strength observation**

| Mix Designation | Split Tensile Strength Test For 28 day Sample (Mpa) | | | Statistical Analysis of Split Tensile Strength | |
|---|---|---|---|---|---|
| | Sample 1 | Sample 2 | Sample 3 | Mean strength (Mpa) | Standard Deviation |
| M25 with 0% PCA | 4.38 | 4.41 | 4.45 | 4.41 | 0.035 |
| M25 with 5% PCA | 4.08 | 4.10 | 4.12 | 4.10 | 0.020 |
| M25 with 10% PCA | 4.27 | 4.29 | 4.32 | 4.29 | 0.025 |
| M25 with 15% PCA | 3.38 | 3.39 | 3.4 | 3.39 | 0.010 |
| M25 with 20% PCA | 2.97 | 2.99 | 3.02 | 2.99 | 0.025 |

The statistical analysis was done by finding mean and standard deviation from calculated 28 day Compressive strength samples of M25 with 0% PCA, 5% PCA, 10% PCA, 15% PCA and 20% PCA samples respectively; it was used to assess the reliability of results. The obtained low standard deviation suggested that the data points are closely clustered around the mean, indicating a higher degree of consistency.

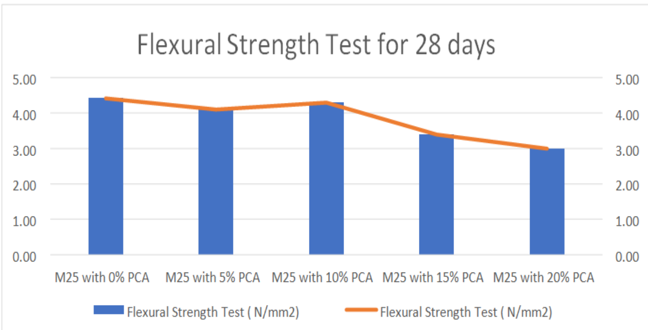


**Figure 7: 28-day flexural strength test graph for different replacement of PCA**

The flexural strength findings of M25 grade concrete with different proportions of replacement of Plastic Coarse Aggregate (PCA) show that the material is definitely affected by the replacement proportion with regards to its capacity to withstand bending stresses. The highest average flexural

 

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strength (4.41 Mpa) was obtained with the control mixture that consisted of 0% PCA, which was used as the baseline of measuring the effect of plastic aggregate incorporation. Surprisingly, the mixture of 10% PCA had a strength of 4.29MPa, which was marginally better than the 5% PCA mix of 4.10 Mpa. This is an indication that low levels of incorporation of PCA could not have a serious impact on flexural performance but could instead provide minimal benefits, possibly owing to increased compaction or better distribution of the particles.

## V. CONCLUSION AND RECOMMENDATION

This study evaluated the performance of M25 concrete incorporating recycled HDPE plastic waste as a partial replacement for natural coarse aggregate. Experimental results demonstrated that the mechanical properties of concrete are influenced by the percentage of HDPE replacement. Workability decreased gradually with increasing plastic content; however, all mixes remained suitable for general construction. The compressive, split tensile, and flexural strengths showed only minor reductions at 5% and 10% replacement levels but declined significantly beyond 10%. The results indicate that 10% HDPE replacement provides the optimum balance between structural performance and sustainability. In addition, HDPE aggregate reduced concrete density, contributing to lightweight concrete production while simultaneously addressing plastic waste disposal issues. Therefore, recycled HDPE can be considered a promising alternative aggregate for sustainable construction applications.

In the previous result showed there are many types of plastic waste (other than HDPE) like (LDPE, PP, PET & Recycled plastic waste) that lead to reduced in density & improve sustainability with acceptable mechanical characteristics for conventional concrete at replacement level (5-15)% provide a limited strength and reduced weight but few studies are seen in a recent year focusing on HDPE plastic aggregate partially replaced with coarse aggregate indicating that limited mechanical performance achieved higher design mix M30 or above at replacement level (5%-20%) to provide balance between strength test (compressive upto 10% & tensile/flexural up to 15%) and lightweight property of concrete. Following these approaches the study adopts an M25 design mix & directly addresses the manufacturing process of HDPE plastic waste that focusing on improvement of HDPE plastic quality, surface treatment & performance when used as a replacement works.

In this research to develop lightweight concrete through recycling and reuse of waste plastic, the effect of natural coarse aggregate partially replaced with plastic coarse aggregate of M25 design mix concrete was studied. The concrete mixes were made with partial replacement of PCA (plastic coarse aggregate) weight ratios of 0%, 5%, 10%, 15% and 20% for NCA (natural coarse aggregate). The mechanical properties, including slump, compressive strength, splitting tensile strength and flexural strength of the concrete produced from the above-mentioned mixtures were investigated. The results in this study can be calculated and summarized as follows.

1. Comparing the difference in weight and percentage of reduction in weight between NCA and PCA in each of the M25 mixes, the substitution of NCA with PCA leads to uniform and significant weight reduction in coarse aggregate of the mixes, with the mix becoming lighter and lighter. The weight difference at the control mix (0% PCA) will be 1149.76 kg with 0% reduction, whereas higher percentages of PCA at 5, 10, 15, and 20 will reduce the weight difference to 1092.27 kg, 1034.79 kg, 977.30 kg and 919.81 kg respectively which corresponds to a weight reduction of 3.21, 6.42, 9.63, and 12.8 This finding confirms that adding more PCA content to the mix enhances the lightweight quality of concrete in a considerable proportion hence proving that PCA has the ability to enhance the lightweight quality of concrete by adding more content without changing the proportions of cement, fine aggregates, water and admixtures.
2. As the proportion of plastic coarse aggregate (PCA) partially replaced by the natural coarse aggregate (NCA) increases the decrease in the slump value of fresh concrete is greater since the dropped values combines with 5, 10, 15, and 20 percent of the PCA gave a mean slump value of 89 mm, 82 mm, 78 mm, and 75 mm respectively.
3. According to compressive strength test result, 0% PCA (31.75 MPa) and 5% PCA (31.62 MPa) give a value that meets or exceeds the target strength of 31.60 MPa whereas 10% PCA (31.24 MPa), 15% PCA (30.17 MPa) and 20% PCA (30.06 MPa) is less than that of the target strength, meaning that a PCA replacement above 5% results in a grad In the meaning of strength and lightweight concrete the general result is that, at 5 percent PCA higher compression strength and percentage decrease in weight as a result of PCA is 3.21.
4. According to the split tensile strength test outcome, 0% PCA (4.40 MPa), 5% PCA (4.09 MPa) and 10% PCA (4.28 MPa) were found to be equal or above the desired strength of 3.50 MPa, whereas 15 PCA (3.38 MPa) and 20 PCA (2.99 MPa) was found to be slightly lower than the desired strength, suggesting that its use at a percentage above 10 reduces tensile strength to levels which In the meaning of power and lightweight concrete the total outcome seen that, enhanced tensile strength at

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10% PCA and percentage weight decrease by PCA is 6.42%.

5. According to flexural strength test outcome found that PCA replacement above 10 percent (0 percent PCA (4.41 MPa), 5 percent PCA (4.10 MPa), 10 percent PCA (4.29 MPa)) gives flexural strength values of equal or lower than the target flexural strength (3.50 MPa) whereas, 15 percent PCA (3.39 MPa) and 20 percent PCA (2.99 MPa) is slightly less than the target flexural strength (3.50 MPa In the term of strength and lightweight concrete the overall result showed that, the higher flexural strength at 10 percent PCA and the percentage decrease in weight caused by PCA is 6.42 percent.

**Recommendations for Future Study**

The mechanical properties of concrete are affected natural coarse aggregate replaced with plastic coarse aggregate at 5% in compressive strength (decrease in concrete weight 3.21%) also 10% replacement in tensile & flexural strength (decrease in concrete weight 6.42%) and therefore it is becomes lightweight density in nature which is suitable use for load bearing structure, non-load-bearing structures such as energy-efficient buildings, partitions, prefab units, eco-pavers, low-traffic roads and floating platforms.

The quality of HDPE plastic prepared through the recycling reuse process can be improved in quality using advanced technology also quality of mix design that may help feasible construction also reduced construction costs as well as saves natural aggregate scarcity, promoting circular economy, smarter waste management, increased environmental footprint that encourages further research into sustainable aggregates for economical concrete construction in civil engineering.

When the manufacturing process of HDPE plastic is carried out through the recycling and reuse of waste plastic at this time the cost estimation is not mentioned. In this study Natural Coarse Aggregate (NCA) is replaced by Plastic Coarse Aggregate (PCA) but the overall cost benefit analysis, durability and long-term performance in terms of concrete is not mentioned and this should be addressed in future efforts.

**CONFLICT OF INTEREST:** The authors would like to state that there is no conflict of interest with regard to this work.

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