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Waste Plastic In Concrete: Review And State Of The Art

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The rapid increase of global plastic waste has been of serious concern for environmental scientists, and it has been a motivating factor for many researchers toward new innovations regarding its recycling and management. The construction industry being one of the largest consumers of natural resources and biggest waste generating industry, and hence it could be the biggest player in utilizing plastic waste into the production of concrete to attenuate this menace. This review investigates the mechanical properties of concrete incorporating different types of waste plastics and their potential application in rigid pavements. The principal objective of the paper is to review and investigate the influence of Polyethylene Terephthalate (PET), High-Density Polyethylene (HDPE), Low-Density Polyethylene (LDPE), Polyvinyl Chloride (PVC), and Polypropylene (PP) as partial replacements of fine aggregates in concrete mixes developed for rigid pavement applications. To evaluate the workability of concrete introduced with waste plastic as a viable partial replacement to fine aggregates and to contribute a sustainable solution to the environment. This paper reviews the current state of research concerning waste plastics in concrete. The review noted variation in the specific outcomes of concrete with plastic waste properties regarding it's the various related mechanical properties. It also pointed to a gap in the line of research regarding issues related to long-term performance and environmental impacts on waste plastic in concrete applications.

Keywords— *Waste Plastic; Concrete; PET; Mechanical Properties; Durability.*

I. INTRODUCTION

Concrete can be justified as one of the largest materials used in construction worldwide, with a range of uses from buildings, bridges, pavements, to infrastructure. This is to say that its flexibility, durability, and relatively low cost per unit have made it number one in a great number of construction projects. This surge in concrete demand is, however, being translated into very serious concerns for its ecological impact, specifically surrounding the reduction of the natural resources and the production of greenhouse gases during the production of cement (Babafemi, Šavija Branko, Suvash, & and Anggraini, 2018).

Researchers have sought different methods of improving the properties of concrete and reducing their environmental footprints. The most important of these recommended practices is the adoption of waste materials, such as recycled plastics, in partial replacement for natural aggregates in concrete (Babafemi, Šavija Branko, Suvash, & and Anggraini, 2018). For example, it has been mentioned that whereas plastic waste is non-biodegradable and creates huge environmental problems, on the other hand, the same plastic waste can replace natural aggregates in concrete production (Shukur, Ibrahim, Al-Darzi, & Salih, 2023).

Various types of waste plastics like the PET, HDPE, and PP — or even electronic waste (E-waste), have been carried out through numerous studies for use on a large scale or as fine and coarse aggregates in concrete (Babafemi, Šavija Branko, Suvash, & and Anggraini, 2018), (Shukur, Ibrahim, Al-Darzi, & Salih, 2023), (Abbas, et al., 2022). Most of these studies have been carried out on the compressive strength, tensile strength, flexural strength, and elastic modulus of concrete containing waste plastics and other performance-related mechanical properties (Babafemi, Šavija Branko, Suvash, & and Anggraini, 2018), (Shukur, Ibrahim, Al-Darzi, & Salih, 2023), (Abbas, et al., 2022), (Jonbi Jonbi, 2019), (R Irmawaty, H Parunh, A A Amiruddin, & Faturrahman, 2020).

In addition, direct incorporation with waste plastics in concrete can also help come up with a solution to the environmental threat that plastic waste causes and at the same time also be helpful to augment the rigidity of other special properties of concrete in pavements applications (Babafemi, Šavija Branko, Suvash, & and Anggraini, 2018). And in such a high-traffic and industrial facility area, they have an area of common application for rigid pavements demanding concrete with high strength, durability, and abrasion resistance against chemical attacks (Shukur, Ibrahim, Al-Darzi, & Salih, 2023). The optimal use of waste plastics in concrete mix design would help produce concrete material for rigid pavement application that can be both sustainable and high performance. (Babafemi, Šavija Branko, Suvash, & and Anggraini, 2018) & (Shukur, Ibrahim, Al-Darzi, & Salih, 2023).

The objective of the following literature review is to present an elaborate summary of the present status of research in relation to the mechanical properties of concrete containing waste plastic and its potential use in concrete. Based on these findings, this review provides elaborative understanding regarding the opportunities and challenges of using waste plastics for concrete. The future research focus in this area is therefore more clearly directed.

II. THE USE OF DIFFERENT WASTE PLASTICS IN CONCRETE

The increasing concerns about the environmental impact of plastic waste are directing researchers toward innovative ways of management and disposal of the same. The non-biodegradable nature of plastic waste, mostly from the packing of goods, has made its disposal a global challenge because the volume of waste being generated daily is just astonishing (Babafemi, Šavija Branko, Suvash, & and Anggraini, 2018). Waste being disposed of on land and in marine environments is associated with major ecological consequences in both terrestrial and aquatic habitats. (Shukur, Ibrahim, Al-Darzi, & Salih, 2023).

Amid these environmental challenges, one of the most insistent demands is for construction materials that are sustainable—capable, in one way or another, of serving to mitigate the negative impacts of plastic waste. This is because of construction being one of the industries that rank highest in consumption of the earth's natural resources; hence, it holds equally promising potential to serve as a major player in the development and adoption of eco-friendly materials (Babafemi, Šavija Branko, Suvash, & and Anggraini, 2018). With this research, the authors attempt to resolve two very vital issues at once by simultaneously incorporating waste plastics in concrete: issues related to the management of plastic waste and reduction of the environmental footprint of construction materials. (Abbas, et al., 2022).

The use of waste plastics in partial replacement of natural aggregates in concrete also engulfs several environmental benefits. First, less plastic waste is available for filling up landfills or polluting the environment (Jonbi Jonbi, 2019). Second, it reduces the demand for virgin natural aggregates, which are generally mined and hence greatly mitigates land degradation and destruction of habitats (R Irmawaty, H Parunh, A A Amiruddin, & Faturrahman, 2020). These may possibly enhance with the usen of waste plastics in concrete its thermal insulating properties. Thus, it may reduce the energy consumed during heating and cooling of buildings. (Babafemi, Šavija Branko, Suvash, & and Anggraini, 2018).

Furthermore, successful application of waste plastics in concrete requires comprehensive knowledge with regards to their effect on mechanical properties and the durability of the material. Researchers have carried out a study on waste plastics of all kinds, including PET, HDPE, PP, and E-waste, to determine their suitability for use as concrete substitute aggregates (Babafemi, Šavija Branko, Suvash, & and Anggraini, 2018), (Shukur, Ibrahim, Al-Darzi, & Salih, 2023), (Abbas, et al., 2022). Some of these studies have reported positive results in the sense that the low percentage incorporation of waste plastic either maintains some mechanical properties or even makes it better, while some pointed at the challenge it poses in that the bond of plastic aggregates with the cement matrix is weak. (Jonbi Jonbi, 2019) & (R Irmawaty, H Parunh, A A Amiruddin, & Faturrahman, 2020)

In this context, different strategies are being considered in research, such as surface treatment of the plastic aggregates, the use of additives, and optimization in mix designs, that can bring about performance optimization in concrete containing waste plastics amidst these challenges (Abbas, et al., 2022) & (Babafemi, Šavija Branko, Suvash, & and Anggraini, 2018). It would thus seem that the construction industry would be moving still closer to the development of truly sustainable, high-performance concrete materials contributing to the concept of the circular economy and lessening environmental impact from plastics waste, if these are to be addressed.

A. PET

Generally, polyethylene terephthalate (PET) is a common waste plastic used as a substitute for the natural aggregates in concrete. The preparation work for PET waste includes collection, cleaning, and shredding the plastic into desirable sizes before mixing it in the concrete (Babafemi, Šavija Branko, Suvash, & and Anggraini, 2018) & (Chandu, 2016). Waste plastic materials were collected first and cleaned for the removal of dust and clay particles before they are fed into a shredding machine to get particles that can pass through a 2.3 mm (about 0.09 in) sieve (Chandu, 2016). Similarly, Ramireddy (2023) has used the PET waste bottles, which were cut into fibres of uniform thickness of 0.13 mm (about 0.01 in) and a mixture of three different lengths: 22 mm (about 0.87 in), 45 mm (about 1.77 in). (Ramireddy, 2023).

Sometimes further treatments or modifications are applied to improve the bond between the plastic aggregates and the cement mixture. For example, Irmawaty et al., 2020, melted and pulverized PET plastic bottles to transform them into aggregates of 20 mm (about 0.79 in) size. Jonbi et al., (2019), adopted a similar approach for their PET waste, where the PET was shredded to thin sheets, while for the polypropylene pipe (PEP) waste, sheets were chopped into 3 mm (about 0.12 in) to 10 mm (about 0.39 in) pieces. Kiss et al. (2020) used PET waste as dispersed reinforcement in the form of flat strips (0.5 × 10 cm) and chips (3 × 3 × 3 cm). (Kiss, 2020).

On the other hand, some mechanical properties performed better at low replacement rates. This increase in compressive strength was noted by the researchers only for very low levels of replacement of PET plastics, being up to 10%, due to the starting points of the presence of the plastic particles, which may convert some of the shear stress into tensile stress, thus consuming energy and delaying failure. Any further amount of plastic substitution can cause decrease in compressive strength. (Babafemi, Šavija Branko, Suvash, & and Anggraini, 2018) & (Kiss, 2020).

Compressive strength among one of the most important mechanical behavior parameters of concrete. Most of the works in this area investigated studies on the compressive strength of concrete specimens with PET waste, including, for instance, Chandu et al. (2016), Ramireddy (2023), Kiss et al. (2020), and Irmawaty et al. (2020). The tests were normally carried out on cylindrical or cubic specimens following standard procedures such as ASTM C39, or its equivalent, at varying days of curing: 7 days, 14 days, and 28 days.

All experimental results from the above works stated that replacement of PET waste as aggregate for the concrete reduced mechanical performance compared to normal or fresh concrete. Generally, the reduction of strength was almost proportionate to the added PET waste amount, and the higher the replacement level, the higher was the strength loss. However, there exist some rare works, for instance, Chandu et al. (2016) and Kiss et al. (2020), which have reported that small increases in the addition of PET waste, up to 10% use, led to slightly improved or comparable mechanical properties against control concrete. This improvement can be attributed to the property of PET fibres and redistribute stresses at a very low addition level. (Chandu, 2016) & (Kiss, 2020). Studies also indicate that the durability of PET waste concrete may have higher water absorption and lower chemical attack resistance, as compared to conventional concrete. They further reported that in such mixtures, the modulus of elasticity decreases in a linear form with an increase in the percentage of plastic aggregates and that the drop in the modulus of elasticity is less compared to the reduction in compressive strength. Still, detailed study needs to be done to understand the characteristics pertaining to the durability of PET waste concrete. In short, the experimental approach used for the evaluation of properties of PET waste concrete are quite uniform, and standard test procedures are used. The results mostly indicate the compromise between the use of PET waste for environmental benefits and losing its mechanical performance. There is a further need to explore optimal levels of replacement and strategies to regain or minimize the loss in strength.

B. HDPE

It is identified by Chandu (2016) that chemical treatments are done to improve the interfacial bond between HDPE particles and the cement paste. This etching of the HDPE particle surface can roughen the structure of the surface and further contribute to the mechanical interlock properties between the particles in the concrete matrix. Such treatment is to reduce the natural slickness of HDPE, which allows reducing the bond strength. (Chandu, 2016).

Particle size was also singled out in achieving the right mix for optimality in concrete properties by both Jonbi et al. (2019) and Chandu (2016). These particles are used for processing recycled HDPE in a manner that would entail the size and shape to be close to the traditional coarse aggregates. There are uniform mixing and workability so that they provide concrete mix. Optimization of size is very important to avoid the particle segregation which can provide sound structural integrity.

This has been instrumental in ensuring proper mixing and integration of HDPE particles in the concrete mixture, using a standard mixing technique. The standard mixing technique has seen to it that the differences observed between this, and the next batch are sufficiently under control, as agreed by Jonbi et al. (2019). That ensures control, and one batch to another is warranted. Curing is done as per ASTM standards. Generally, the method of curing involves curing the concrete specimens in water at controlled temperatures, simulating actual environmental conditions. Both studies used experimental techniques, such as substituting part of the natural aggregates with treated HDPE waste plastics. In the first one, it involved heated aggregates of shredded HDPE waste, while the latter replaced the coarse aggregates using HDPE shredded plastics at percentages of 15%, 20%, and 25%.

Both studies have attempted to compare some properties of conventional concrete that contain HDPE waste plastics. Further use of plastic-coated aggregates done by Chandu et al. concludes that around 10,00,000 carry bags can be effectively used in giving strength to roads and saving roads from the formation of potholes in a 1 km long, 3.375 m wide single-lane road. Jonbi et al. noted that as the percentage of substitution level of HDPE waste in concrete was increased, its effect on slump value was obtained to be decreasing, indicating the decrease in workability. The compressive strength of concrete for 15%, 20%, and 25% replacement with HDPE was found to be 100%, 58%, and 51%, respectively, at 28 days. Tensile strength was also found decreasing with increasing HDPE contents that were 70%, 61%, and 50% of reference concrete at 15%, 20%, and 25% replacement, respectively.

These findings suggest that HDPE waste provides better mechanical performance, but the best percentage of replacement must be defined to assure the performance expected for some specific applications, such as rigid pavements. The best percentage of HDPE waste replacement in the case of concrete is very critical for several reasons: 1) Optimized concrete performance with an optimal level of 15% to attain maximum mechanical properties and at the same time minimize the ill effects of incorporating HDPE waste. This ensures a balance in that the concrete will still be robust and compatible with its applications, rigid pavements, and not affect quality and durability. (2) HDPE waste proves to be cost-effective when utilized into the concrete mixture at an optimum level; it reduces the consumption of natural aggregates by concrete, therefore saving a lot of money. This will further prove to be effective environmentally, as it saves people from quarrying and mining these natural resources. This promotes sustainability in construction practices with emphasis on the topmost economic performance.

Conclusively, properties of the aggregates had been improved with the use of plastic-coated aggregates; hence, even the weak aggregates could be utilized for construction purposes. Jonbi et al. had similar conclusions, they ascribed the decrease in compressive and tensile strengths to low adhesion between the cement paste and the surface of the HDPE particles, which were smooth and shiny.

These data and results indicate that the works used HDPE waste plastics in concrete either as a coating or to replace part of the coarse aggregate. Whereas the former resulted in an enhancement of the strength and durability of the roads because of the addition of plastic-coated aggregates, the latter showed a loss of the consistency and mechanical properties when replacing the coarse aggregates with HDPE pellets. These would call for further considerations of the processing methods to be used and the incorporation techniques when one is striving to attain performance and sustainability when using HDPE waste plastics in concrete.

C. LDPE

In construction and materials engineering, there is increasing interest in waste plastics, particularly with low-density polyethylene (LDPE), to concrete. The LDPE is reported as an aggregate to the fine one to impart partial properties of the fine aggregate to the concrete mix. The application would allow the potential enhancing the mechanical properties and of an eco-friendly construction of rigid pavements. With the following study, the existing knowledge in the mechanistic materialistic interpretation of the use of LDPE will be advanced. (Flomo, 2013) (Chaudhary, 2014), (Mohammed A. S., 2020).

Manish et al. (2014) conducted research on the influence of LDPE waste on the mechanical properties of concrete. They utilized shredded LDPE, sourced from waste plastic bags, as a partial replacement for fine aggregates in concrete mixtures. The LDPE was granulated into small particles and mixed with cement, coarse aggregates, and water to produce concrete specimens. The study evaluated the compressive strength and split tensile strength of these specimens at 7 days and 28 days of curing. The results demonstrated an increase in compressive strength from 21.8 N/mm2 at 0% LDPE to 23.6 N/mm2 at 0.8% LDPE after 7 days, and from 26.67 N/mm2 at 0% LDPE to 36.07 N/mm^2 at 0.8% LDPE after 28 days. The split tensile strength also showed an increasing trend with the addition of LDPE. The study concluded that incorporating waste LDPE in shredded form can enhance the mechanical properties of concrete while contributing to environmental sustainability by reducing plastic waste (Flomo, 2013).

Some research work has been conducted on behaviours of concrete and mortar by Mohammed et al. (2020), containing LDPE waste as partial replacement of fine aggregate. The LDPE waste to replace the fine aggregate in the concrete and mortar mix was 2%. The LDPE waste granules were procured from waste food boxes, which were cleaned and sorted. These granules were combined with cement, coarse aggregates, and water to prepare the concrete specimens and with cement and water for the mortar specimens. The specimens were then tested appropriately for compressive strength, split tensile strength, and ultrasonic pulse velocity at a different replacement level of the LDPE waste. (Mohammed A. S., 2020).

The results showed a decrease in dry density and compressive strength with increasing LDPE content in both concrete and mortar. Specifically, the minimum dry density was 2240 kg/m^3 for concrete with 30% LDPE and 2101 kg/m^3 for mortar with 25% LDPE. Compressive strength dropped to 18.70 MPa in concrete with 30% LDPE and to 24.61 MPa in mortar with 25% LDPE. Similarly, split tensile strength and ultrasonic pulse velocity decreased with more LDPE content. Notably, the failure mode of the materials shifted from brittle to more ductile with the addition of LDPE, suggesting potential benefits in applications requiring enhanced ductility. (Flomo, 2013).

All these studies collectively show the potential for employing waste LDPE as partial replacement for fine aggregates in concrete mixtures, particularly in rigid pavements. Generally, processing for LDPE waste involves either shredding or granulating the waste plastic to form small particles to be mixed with other ingredients for concrete. Some even took a step further to subject it to additional treatment, for instance, dissolution of the LDPE in a solvent and rapid cooling to form powdered LDPE, as in the case of Flomo, 2013. Generally, some of the experimental tests commonly used in studying the mechanical properties of LDPE-incorporated with concrete are compressive and split tensile strength tests, studies using ultrasonic pulse velocities, and others. In these methods, the feasibility and performance of using LDPE in concrete structures are assessed. (Flomo, 2013)

A significant change in the role of mechanical properties was observed on comparative analysis of concrete with and without waste LDPE. Inclusion of LDPE tends to reduce compressive strength and density but can increase fracture toughness and ductility. This varies with different studies, and the optimum level of LDPE to get the better properties also varies among studies. For instance, Flomo (2013) recorded an increment in fracture toughness for percentages up to 20% LDPE; Manish et al. (2014) recorded from 0.8% LDPE an improvement in tensile strength; while Mohammed et al. (2020) recorded that the compressive strengths and densities weakened compared to the increase in LDPE content. This therefore means that the proportions of LDPE need optimization with caution for the requirement of the desired property enhancement in applications.

D. PVC

Most of the research focused recently on developing sustainable construction materials by incorporating plastic waste, especially polyvinyl chloride (PVC), into concrete, and recycling plastic waste. The work addressed the experimental methods suitable for both ways of utilizing such waste plastics into the concrete and their harmful effects on the mechanical properties of the concrete.

Usually, PVC waste is converted into granules or powder form by shredding or crushing plastic in the preparation of concrete. Replaced fine and coarse aggregates with shredded PVC sheets with particles of size 9.5 mm (about 0.37 in). Belmokaddem et al. shredded PVC granules from tubes and pipes and were classified into fine (0-3 mm) and medium (3-8 mm) aggregates. Several researchers, such as Manjunatha et al. have used powdered PVC waste as replacement cement. Based on the waste plastic size and shape of the PVC waste, it majorly affected the fresh and hardened properties of concrete. (Azline, 2023).

Some of the experimental techniques used to evaluate the properties of the concrete containing PVC waste include slump tests for workability, compressive strength, splitting tensile strength tests, flexural strength tests (modulus of rupture), and elastic modulus measurements according to different codes, ultrasonic pulse velocity (UPV) , and water absorption tests (Azline, 2023) & (Mohammed A. A., 2019).

It has been found out through studies conducted for comparison of concrete properties with and without PVC waste, that incorporation of PVC, in general, decreases the mechanical properties. Mohammed et al. found out that up to 30% replacement of fine or coarse aggregates with PVC resulted in acceptable compressive strengths (30-40 MPa); however, high replacement levels made a huge strength reduction. Azline et al. reported a decrease in compressive strength by 23% for 25% replacement and by 67% for 50% replacement. This reduction in strength was linked to the smooth surface and hydrophobic nature of PVC, which normally weakens the bond between the plastic and the cement matrix. (Azline, 2023)& (Mohammed A. A., 2019).

Therefore, optimization techniques are of paramount importance for the determination of the best dosage and combination of plastic wastes, such as PVC, in concrete to make compromise between the mechanical properties, durability, and the environmental benefits of the resulting material. Some work has been done on various optimization methods to obtain the best mix proportions for concrete containing PVC waste. Azline (2023) and Azad Mohammed (2021) did work on the impact strength and behaviour of normal strength concrete incorporating shredded PVC waste aggregate or PET waste fibre. Although no formal optimization techniques were used in the study, it was a good source of information about the best dosage of PVC waste aggregate, which can be mixed up to maintaining a level of acceptable impact strength. Their data shows the substitution of fine aggregate by PVC waste up to 30% showed only a moderate reduction in impact strength. However, higher replacement levels severely deteriorated this property; therefore, we need to find some dose level of PVC waste, which can make some compromise between these two factors, which are mechanical properties and environmental benefits.

Mohammed A., (2021) studied the behaviour of normal strength concrete with shredded PVC waste aggregate or PET waste fibre in terms of impact strength. The first crack impact strength, as well as the ultimate load impact strength, shows reduction with an increase in PVC waste percentage, with a reduction of up to 84% at 45% replacement for fine aggregate with PVC waste. The reduced impact strength was associated with an increase in flaws and cavities in the interfacial transition zone between the hardened cement paste and PVC aggregate particles, from where the cracks could easily initiate and propagate.

The rheological characteristics basically take over and manage the processes of mixing, placing, and finishing of the concrete with waste plastics; some of them are slump, workability, and segregation resistance. A number of studies have investigated the influence of PVC and other plastic waste on these properties, with an emphasis on implications for practical applications of these materials in construction (Azline, 2023). Slump and workability are essential rheological properties that determine the ease of mixing, placing, and compacting fresh concrete. Mohammed et al. (2019) investigated the effect of shredded PVC waste on the slump of concrete. They had outcomes indicating that the use of PVC waste as a partial replacement of fine aggregate caused a slight slump to decrease at 45% replacement, sudden slump drops at 65% replacement and a sticky mix at 85% replacement. The reason for that was the increase in the specific surface area of PVC particles that required more water to keep the workability intact (Mohammed A. A., 2019). Likewise, Mohammed Azad (2021) investigated the effect of PVC waste aggregate on the workability of concrete. The study showed that there was a gradual decrease in the slump due to the replacement of the fine aggregate with the PVC waste. (Mohammed A. A., 2021). That was the effect of the cracks and cavities between the hardened cement pastes and PVC aggregate particles that created a weakened transition zone and adversely affected the workability of the mix. In this regard, another very important property of rheology affecting the homogeneity and quality of concrete is the resistance to segregation. Belmokaddem et al. have conducted a detailed study on the effect of PVC waste aggregate on the segregation resistance of concrete. The study confirmed that with the addition of PVC waste enhanced the mix's resistance to segregation. It was attributed to better packing of the particles in the plastic's presence with a reduced density of the added particles. However, authors also reiterated that the mix's resistance to segregation with the addition of PVC waste was dependent on the replacement level and the grading of the plastic particles in the mix. In some studies, the effect of inclusion of plastics on the mechanical properties of concrete indicated that addition of plastics can increase the tensile strength of concrete (Azline, 2023). All these rheological properties will have implications on the placing, mixing, and finishing of concrete with plastics added in it. For example, the reduction in slump values or workability for higher replacement levels of PVC waste will demand adjustments in the mix design, like the water content of the mix and the application of plasticizers to achieve desired consistency. However, on a positive note, better resistance to segregation in the mix will ensure easier placement and finishing of concrete with plastics in it and may reduce the risk of honeycombing and provide a better surface finish to the concrete (Azline, 2023).

An important area of study is related to the concrete's long-term durability containing PVC and other plastic waste in considering the feasibility of use in construction applications. Some researchers have been conducted on the durability aspects of concrete produced with waste plastics, including shrinkage, creep, thermal properties, and resistance to attack of aggressive environments. These would help to know the way in which the lifespan and performance of concrete structures could be affected under different environmental conditions (Azline, 2023). It is also of vital importance to study the durability of concrete structures against aggressive environments like chloride ion penetration and sulphate attack. It was stated that the chloride ion penetration resistance of concrete containing PVC waste as a partial replacement of fine aggregate was explored by Senhadji et al. The results showed a reduction in the chloride ion penetration depth because of the incorporation of PVC waste, attributed to the better pore structure and the reduced permeability of the concrete. However, the authors considered that the effectiveness of the PVC waste in improving chloride ion penetration resistance depends on the percentage replacement, and further research needs to be carried out to assess its long-term performance (Azline, 2023)and (Mohammed A. A., 2019).

The environmental impact of adding waste plastics, which include PVC and PET to the concrete, is among the most critical reasons that have attracted a vast interest in the subject over the last few years. In most cases, studies where the life cycle analysis (LCA) and carbon footprint of this sort of concrete are done to cite some few benefits and challenges while using a PVC waste containing concrete (Azline, 2023). Based on all these case studies, one could see that the use of PVC in concrete is a practical solution to mitigate environmental related issues and create new sustainable construction material. Still, in general, the addition of PVC can adversely affect the mechanical properties of the concrete, particularly when considering its usage in higher replacement level, using it in proper methods with the right particle size and shape. In addition to this, good interfacial bonding between PVC waste and the cement matrix is highly effective to enhance concrete performance. Therefore, more studies are necessary to improve the compatibility of concrete with PVC waste so that it can be widely used in construction applications. Besides that, Azad Mohammed (2021) also mentioned the influence of the concrete containing PVC waste aggregate over the impact strength and behaviour of the concrete since this is one of the most significant concrete properties to predict the durability of concrete structures that are intended to be used under dynamic loading conditions (Mohammed A. A., 2021).

E. PP

The waste Polypropylene PP is collected and then processed to use in concrete, and this starts with its collection, sorting, and cleaning for eliminating contaminants; (Islam, 2021), (Chandu, 2016). The plastic, when cleaned, is shredded, or crushed into much smaller particles or pellets of the desired size, which is typically 1-6 mm; (Paglia, 2023), (Chandu, 2016); (Jonbi Jonbi, 2019). Extra treatments have been applied in some studies e.g., heating the plastic to enhance its ability to bind with the cement matrix; (Chandu, 2016).

Some of the experimental techniques used in the literature to evaluate the properties of concrete comprising waste PP include tests for workability through slump tests, compressive strength, split tensile strength, and flexural strength (Islam, 2021) (Jonbi Jonbi, 2019) (Chandu, 2016) (Paglia, 2023). The other durability-related parameters that have been studied include water absorption, carbonation resistance, and freeze-thaw resistance (Paglia, 2023). These are long-term durability tests for concrete made of PP waste, which verify both the mechanical and long-lasting properties of the material.

The w/c ratio is vital in determining workability, strength, and durability for concrete. In concrete with waste PP, the optimum w/c ratio that can assure adequate workability without significantly affecting the concerned mechanical property is thus important. Islam (2022) worked on the effects of the w/c ratio on the compressive strength of PP concrete and showed that the highest strength was obtained in the case of a water-cement ratio of 0.42, as compared to 0.48 and 0.57, which are higher. That is, for a higher strength of PP-modified concrete, the w/c ratio should preferably be on the lower side. Simultaneously, it should not be made too low because that may affect the workability of the concrete mixture which can make it challenging to place and compact. As a result, a critical balance in the workability-strength requirement with a selected w/c ratio for concrete with waste PP is to be obtained.

The gradation of the aggregates and the packing density, workability, and mechanical properties of the concrete depend much on each other. Where, in applying waste PP, the gradation of the plastic particles and the natural aggregates must be considered. (Chandu, 2016) reported that the utilization of PP particles that would pass a 2.36 mm sieve would improve the compressive strength of concrete for a certain replacement level. This means that using finer PP particles will likely increase the packing density and reduce the voids in the concrete's matrix. Furthermore, this will relatively improve the mechanical properties of the concrete. Nevertheless, excessive proportions of fine PP particles improve the specific surface area and will result in workability problems and potential strength reduction problems. Thus, it is important to optimize the aggregate gradation in reference to the size and proportion of the plastic particles and the natural aggregates to achieve a balance of workability and mechanical properties.

Admixtures can be utilized to control the physicochemical properties of concrete containing waste PP, including workability, setting time, and durability. Jonbi et al. reported that the use of superplasticizers increases significantly the workability of PP-containing concrete, hence allows higher plastic replacement levels without affecting the flow characteristics of the mix. It was also stated that using admixtures, such as the silica fume, enhances the dispersion of PP particles in the concrete matrix, leading to an interface with good bonding and good mechanical properties. On the other hand, Paglia and Paderi reported the potential use of superplasticizers and other admixtures for overcoming the workability issue of PP in a concrete mixture. The desired properties in the PP-modified concrete for use in rigid pavements can be obtained by optimizing the mix design after selecting-admixing proper admixtures.

Islam (2022) reported gain in compressive strength of 39% when the replacement was coarse aggregates for 10% PP, but this trend gets reversed at a higher level of replacement. In a similar manner, Chandu et al. (2016) reported that there was an increase in compressive strength level of 10% PP and a decrease in 20 and 30% substitution levels. According to Jonbi et al. (2019), an optimal PP level of 10% can get 85% of the compressive strength of reference concrete at 28 days. These results once again emphasize the most critical effect of the level of replacement to conclude anything on PP modified concrete performance. Tensile and flexural strengths of PP modified concrete Tensile strength. The study of Chandu et al. (2016) showed an increasing trend in split tensile strength with levels of PP addition up to 7.5%. This enhancement of tensile properties with moderate levels of PP addition means that the tensile integrity of the matrix increases in cases where PP has been used. On the other hand, Jonbi et al. (2019) showed a depleting trend in the levels of tensile strengths with increases in the level of PP addition. This depletion indicates a possible compromise of tensile integrity, while the level of PP content is increasing. According to Paglia & Paderi (2023), an increase in flexural strength was noted with PP addition up to a 7.5% substitution level. This means moderate quantities of substitute can in fact, enhance the flexural capacity of the matrix. Summary and conclusions. The most critical observation from this study was that the PP content was essential as a non-uniqueness level of substitute for giving varying effects on different properties of concrete, depending on what form of strength was considered.

When considering the use of waste polypropylene (PP) modified concrete in rigid pavement applications, it's essential to assess the implications on the overall pavement design. The incorporation of PP can influence various design parameters such as slab thickness, joint spacing, and reinforcement requirements. These changes can affect load transfer efficiency, crack resistance, and ride quality of the rigid pavement. Understanding these impacts is crucial for optimizing pavement performance and ensuring long-term durability and functionality. The thickness of the concrete slab is a critical factor in the design of rigid pavements, as it directly influences the pavement's load-carrying capacity and long-term performance. Chandu et al. (2016) investigated the compressive strength of concrete with PP and found that the addition of PP up to 10% resulted in improved strength compared to the control mixture. This suggests that the use of PP-modified concrete may allow for a potential reduction in slab thickness while maintaining the required strength and durability. However, it is ideal to note that the actual reduction in slab thickness would depend on many factors, such as the specific mix design, traffic loading conditions, and subgrade support. Therefore, a comprehensive analysis considering these factors should be conducted to determine the appropriate slab thickness when using PP-modified concrete in rigid pavements.

Producing normal aggregates like sand and gravel is energy-intensive, involving huge greenhouse gas emissions and carrying a major share of the carbon footprint of the construction sector. However, using PP waste as an aggregate will reduce the carbon footprint from normal aggregate production. This is because, on one hand, the waste of plastic exists in most cases, and on the other hand, the requirement after processing is much lower than it should be, considering the nature of materials in which extraction and transportation are incurred. This would not only help reduce the volume of waste materials but would also move further in creating an approach toward sustainability in the construction industry (Islam, 2021).

This means that partial replacement of aggregates with waste PP in concrete may recycle plastic waste material and reduce demand for natural resources. Obviously, mechanical properties and durability of PP-modified concrete will depend on level of replacement, particle size, and treatment of plastic. In general, the average range of 5–10% of PP contents could maintain or even provide higher strength properties, while percentages above this generally led to performance regression. There is therefore a need for further research in some areas to include mix design optimization and some challenges, such as the weak interfacial bonding between the plastic and the cement matrix.

III.IMPACT OF DIFFERENT PLASTIC WASTE ON MECHANICAL PROPERTIES

As illustrated in Table 1, different types of waste plastics added to concrete have been increasingly being subjected to review in the reviewed literature, such as PET, HDPE, PVC, PP, and LDPE, for the further improvement of the mechanical properties toward sustainable construction. In this research, the treatment given to plastic waste is cutting it into fragments, pelletizing the waste and the treatment of the surface. The fact that the influence of the waste plastics on the concrete composition does cause some loss of workability and variation in the mechanical strength properties, especially at higher replacement levels, has been stated in most of the works. They have, however, been able to come up with the humanly optimized replacement percentages for each of these plastics thereby balancing performance and environmental benefit. It was reported that concrete strength was kept or was raised when replaced up to 10% PP or HDPE. The superficial adhesion between the plastic waste and the cement matrix gives the appearance that this variable might be important in developing the mechanical properties of the concrete. Surface treatments, such as chemical etching or coupling agents, would likely be used to improve bond by increasing it and improve the concrete behaviour.

However, reviewed studies are useful in enhancing human knowledge regarding the use of waste plastics in concrete but still contain gaps in human understanding of the long-term durability and environmental impact of these materials. Further research shall also be required for the size and shape of the added plastic mixture to concrete during mix designs, and its performance testing in concrete under different environmental conditions. On top of that, most of the research work has been focused on the utilization of only one kind of plastic waste in concrete. Overall, research is required to be carried out on the synergistic mixing of different kinds of plastics and their optimized percentage to achieve the target optimum value of mechanical properties desired along with some environmental benefits.

TABLE I MAJOR FINDINGS OF PREVIOUS RESEARCH

Author	**Materials Used**	**Findings**
Chandu et al. 2016	- Waste plastic (LDPE, HDPE, PP) - Cement (53 grade OPC) - Coarse aggregate (20mm, 10mm) - Fine aggregate (2mm)	- Using plastic-coated aggregates improved the properties of aggregates, allowing the use of weak aggregates in construction - A 1km long, 3.375m wide single lane road using plastic-coated aggregates could utilize 10,00,000 carry bags.

Jonbi et. al 2019	- HDPE plastic pellets - PP plastic pellets - Cement (OPC Type) - Coarse aggregate - Fine aggregate	- Optimal replacement percentages: 10% for PP and 15% for HDPE (based on compressive strength) - Increasing plastic waste content reduced workability, compressive strength, and tensile strength - HDPE performed worse than PP due to its smooth, shiny surface.
Mohammed et. al 2019	- Shredded PVC sheets (up to 9.5 mm) - Cement - Natural fine and coarse aggregates - Water	- p to 30% of fine or coarse aggregate can be replaced with PVC aggregate without significantly compromising strength - Workability decreases with increasing PVC aggregate content - Density and water absorption are not significantly affected up to high replacement ratios.
Azad Mohammed 2021	- Shredded PVC sheets - PET waste fibers (20 mm and 40 mm) - Cement - Natural fine and coarse aggregates - Water	- Addition of 20 mm PET fibers at 0.75% enhanced impact strength, but higher dosages led to strength deterioration - Replacing fine aggregate with PVC waste reduced impact strength, reaching 84% decrease at 45% replacement.
Azline 2023	- PVC plastic waste (pipes, sheets, cables, etc.) - Cement - Natural. aggregates	- Physical characteristics of PVC aggregate affect workability and microstructure of cement composite - PVC aggregate can replace coarse aggregate up to 30%.
Flomo 2013	- Powdered LDPE from water sachets - Cement - sand - water	- Fracture toughness increased by 6.12% at 5% LDPE, 6.88% at 10% LDPE, and 24% at 20% LDPE - Compressive strength decreased with increasing LDPE content
Manish et al. 2014	- Shredded LDPE from waste plastic bags - Cement - coarse aggregates - water	- Compressive strength increased from 21.8 N/mm2 at 0% LDPE to 23.6 N/mm2 at 0.8% LDPE (7 days) - Split tensile strength also increased with LDPE addition.
Mohammed et al. 2020	- LDPE waste granules from recycled food boxes - Cement	- Dry density and compressive strength decreased with increasing LDPE content

	- coarse aggregates - water	- Split tensile strength and ultrasonic pulse velocity also decreased.
Islam 2020	-PP - PET waste - aggregate -cement - sand - water	- PP at 10% increased compressive strength by 39%, PET reduced strength, both reduced workability and density.
Pavlík et al. 2019	-Crushed PP waste - cement, sand, water	- PP reduced density, strength, and elastic modulus, improved thermal insulation, weak interfacial bonding observed.
Paglia & Paderi 2023	- Recycled PP/PE pellets - cement - aggregates - water	- 4% PP/PE slightly reduced strength and density, increased water permeability, decreased freeze-thaw and carbonation resistance
Ramireddy 2023	- Waste plastic bottles - M20 grade concrete (1:1.5:3 mix)	- Compressive strength increased up to 5% plastic replacement compared to control at all ages. - 10% replacement gave higher early strengths but lower 28-day strength than 5%.
Kiss et. al 2020	- Recycled PET packaging waste in the form of flat strips and chips	- Density of concrete with PET was within acceptable range - Compressive strength increased by ~9% with both PET strips and chips compared to plain concrete.

A. PET AND MECHANICAL PROPERTIES: COMPRESSIVE STRENGTH

The addition of PET waste in aggregate has been generally observed to result in the alteration of the compressive strength of concrete, as shown from the studied reviews. The reduction in compressive strength occurred with most of the increases in PET content in most studies, where the reduction depends on the size, shape, treatment, replacement levels, and mix design.

Ramireddy (2023) concluded that compressive strength increased for concrete containing 5% and 10% replacement of coarse aggregate with waste plastic bottles, with strength surpassing the targeted mean strength for M20 grade concrete at the age of 28 days , similarly, Dawood et al. (2021) further classified effects on compressive strength of substituted PET particles into three classes: 0-10% (huge increase), 10-15% (strength continued to be positively affected), and 15-20% (strength reduction). (Dawood, 2020) & (Ramireddy, 2023). Figure 1 shows effects of the mechanical properties of concrete with PET substitution level.

The compressive strength in concrete containing PET waste depends on several important factors: replacement level, size, and shape. While moderate levels of replacement have been established to improve or maintain compressive strength up to about 10%, higher levels of replacement will generally reduce the strength.

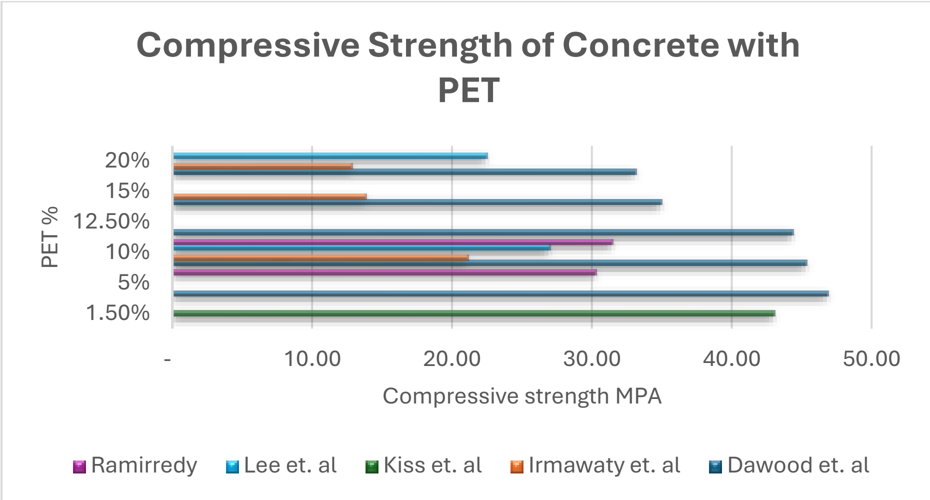

Figure 1: Effect of PET on Compressive Strength

B. HDPR AND MECHANICAL PROPERTIES: COMPRESSIVE STRENGTH

As shown in figure 2, replacing natural aggregates with high-density polyethylene in concrete decreased compressive strength below that of controlled mixes without high-density polyethylene.

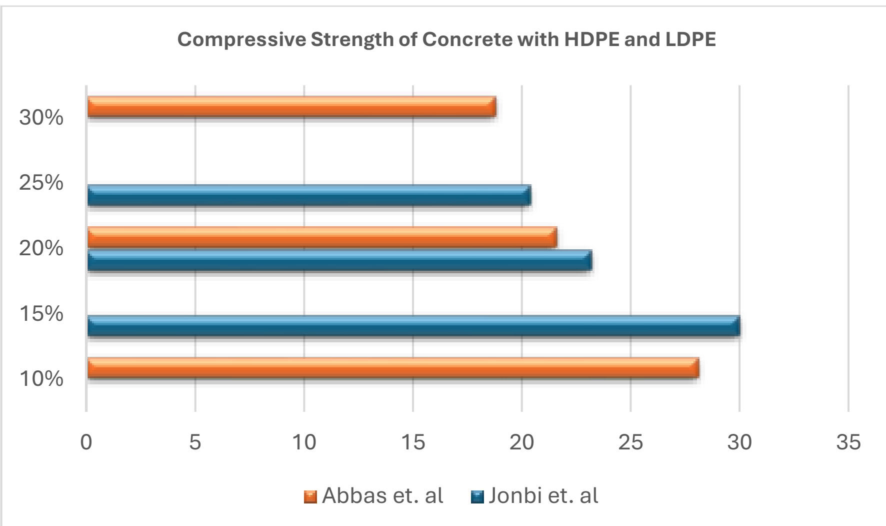

Figure 2: Effect of HDPE and LDPE on Compressive Strength

The compressive strength decreases with an increase in the HDPE content; it decreased by 21%, 39%, and 47% for HDPE replacement levels of 10%, 20%, and 30%, respectively. (Islam, 2021), similarly, the compressive strength of concrete by Abbas et al. (2022) with 10%, 20%, and 30% of uncoated HDPE used as a partial replacement of coarse aggregates resulted to 28.1 MPa, 21.6 MPa, and 18.8 MPa, respectively, as compared to 35.6 MPa for the control mix. (Abbas, et al., 2022).

Chandu et al. have reported using 2.5%, 5%, and 7.5% replacement levels of LDPE plastic waste with M35 grade concrete. The maximum 28-day compressive strength (36 MPa) at the 5% replacement level was observed. For both split tensile strength and flexural strength, the increase with the increasing plastic content levels was observed, in which at 7.5% replacement the rise was to 5.9 MPa and 6 .75 MPa, respectively, at 28 days.

C. PVC AND MECHANICAL PROPERTIES: COMPRESSIVE STRENGTH

As shown in figures 3 and 4, there is a clear reduction in the concrete compressive strength due to PVC and PP waste replacing aggregates. The replacement level and the type of replaced aggregates, either fine or coarse, are determined based on the reduction in strength.

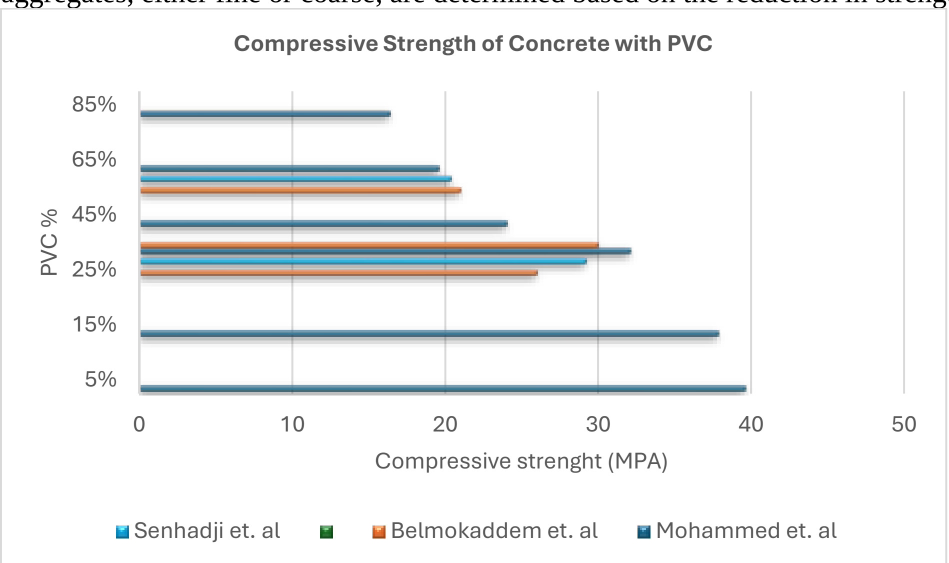

Figure 3: Effect of PVC on Compressive Strength

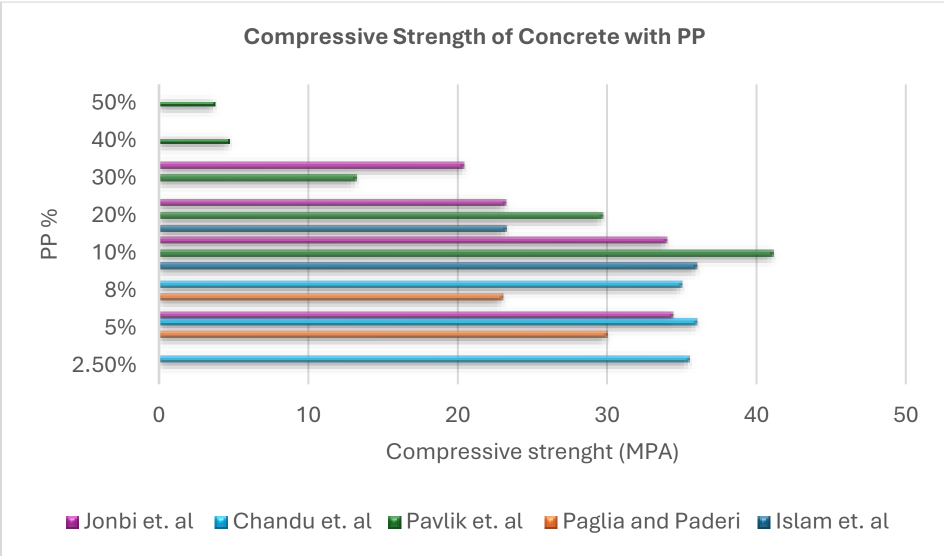

Figure 4: Effect of PP on Compressive Strength

According to the study by Mohammed et al., there is a steady trend of decrement in compressive strength with an addition of PVC content. Strength loss reached 60% and 80% after replacing 85% of PVC content of fine and coarse aggregate,(Mohammed A. A., 2019) respectively. According to the authors, a replacement of over 45% of the respective type of aggregate by PVC has been the reason for the reduction of over 20% of its compressive strength. Similarly, Azline et al. also cited such research related to the usage of PVC waste in concrete, and the authors say that Belmokaddem et al. reported the compressive strength of concrete with substitution level of 25% and 50% PVC aggregate to be 23% and 67% less than that of a control sample, respectively (Azline, 2023).

The investigation by Jonbi et al. used 5%, 10%, and 15% levels of PP replacement and 15%, 20%, and 25% levels of HDPE for a target strength of 25 MPa mix. The optimum levels of PP and HDPE replacement for compressive strength were 10% (85% of reference) and 15% (100% of reference) respectively at 28 days. Tensile strengths at 28 days decreased with increasing plastic content for both PP and HDPE. Similarly, Pagalia and Paderi used some of the replacement levels as 4% and 8% of PP/PE plastic granulates together with a reference concrete of class C30/37. They found a 4% reduction in the compressive strength of 28 days to around 30 MPa, while an 8% replacement further declined it to about 23 MPa. The elastic modulus was 25-28 GPa for the concrete with plastic granules (Paglia, 2023).

Different types of waste plastics added to concrete have been increasingly being subjected to review in the reviewed literature, such as PET, HDPE, PVC, PP, and LDPE, for the further improvement of the mechanical properties toward sustainable construction. In this research, the treatment given to plastic waste is cutting it into fragments, pelletizing the waste and the treatment of the surface. The fact that the influence of the waste plastics on the concrete composition does cause some loss of workability and variation in the mechanical strength properties, especially at higher replacement levels, has been stated in most of the works. They have, however, been able to come up with the humanly optimized replacement percentages for each of these plastics thereby balancing performance and environmental benefit. It was reported that concrete strength was kept or was raised when replaced up to 10% PP or HDPE. The superficial adhesion between the plastic waste and the cement matrix gives the appearance that this variable might be important in developing the mechanical properties of the concrete. Surface treatments, such as chemical etching or coupling agents, would likely be used to improve bond by increasing it and improve the concrete behaviour.

IV. CONCLUSIONS

Another way that will assist in large sustainable construction practices and the circular economy is the partial replacement of fine aggregates with waste plastics in concrete mixes. This technique enables the reduction of the environmental impact caused by plastic waste and assists in developing new, innovative, and eco-friendly concrete materials that can be used on rigid pavement applications with waste plastics, among others. PET, HDPE, LDPE, PVC, and PP are underutilized in the recycling stream. This paper reports the new light that will be shed on a comprehensive literature review, procedure adapted for the research, and its experimental plan on the influence of waste plastics on the mechanical properties of concrete. The performance of concrete, that will be derive from the outcome of the study, is, without doubt, extremely variable due to the influence of the plastic waste, and it lays a great weight on the considered situation: it should be investigated for the key parameter in a systematic and definite way.

Compressive strength would vary with the types and percentages of the waste plastic used for incorporation. This might lead to a slight enhancement in strength. The higher replacement levels might compromise the strength. Tensile and flexural strength- the wastage plastic addition may bring in some of the effects on tensile strength and flexural strength for concrete mixes. Both the extent and nature of the effect are to be seen from the planned experiments.

Environmental friendliness- this is likely to help in curbing the discarding of plastic waste into the landfills and, hence, shall save the natural courses of material from further degradation due to plastic waste disposal. Besides that, mechanical performances of the concrete mixes and their suitability for use in the rigid pavements will be appraised in respect to the expected environmental benefit potential.

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