A review of Use of Waste Plastic as Binder Replacing Cement in Creation of Construction Elements

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Abstract- Disposal of plastic waste accumulated in the 21st century is a major challenge worldwide. In India, about 3.5 million tons of plastic waste is produced annually causing enormous environmental hazards. The decomposition rate of plastic waste is very slow, thus it is not biodegradable and poses a major problem in waste management and waste disposal. Cement as a binding material in the construction Industry is quite popular. The cement consumption per capita in India is also rampant and cement manufacturing industry also has adverse environmental Impact. If the plastic waste is used to replace the cement as a building material or binder then there is a double possibility of mitigating the environmental hazard and help in economy. The purpose of this work is to review the scientific literature related to replacement of cement in the construction Industry in general and manufacturing of the paver blocks in particular.

Keywords: Plastic Waste; Plastic Paver Blocks (PPB); Plastic Waste; Low Density Poly- Ethylene (LDPE)

1. INTRODUCTION

The perceptibility of plastic waste is increasing enormously because of its incremental and indiscriminate use in recent decades. Its natural decomposition may take thousands of years and it causes negative impact on the surrounding environment and human health. The amount of plastic waste that has accumulated in the 21st century poses major challenge to its disposal worldwide. In India, about 3.5 million tons of plastic waste is produced annually which poses a major problem in waste management and waste disposal. At the same time, cement consumption as a binding material in the booming construction and infrastructure Industry is quite rampant in India. The estimated cement consumption per capita in India is also rampant. In the year 2022 the consumption has become 379 Million Metric Tons (Statistia, 2023). The cement industry contributes to around 7% of global carbon emissions. Particulate matter (PM) emissions from cement plants are very high, and cement is understood to be the most polluting industry in the world. (Sreenivasan, 2022) Thus if the plastic waste is used to replace the cement as a building material or binder then there is a double possibility of mitigating the environmental hazard and help in economy. This calls for research by the academicians as well as the construction industry to find innovative solutions and promote the use of plastic waste in concrete. The purpose of this work is to review the scientific literature related to replacement of cement in the construction Industry in general and manufacturing of the paver blocks in particular.

Konin (2011) presented an experimental study to find the possibility of using plastic waste as a binding material instead of cement in the manufacturing of roofing tiles. The study bears on plastics with a polypropylene basis. Plastic waste is carried to melt and mixed with a varying proportion of sand (variation between 50 and 80% in weight). Five compositions of tiles characterized by their proportion in plastic waste of 0% (tiles in micro-concrete), 20, 30, 40 and 50% were studied. The measuremens of physical and mechanical properties show that plastic waste tiles whose proportion in plastic is 40%, give better results than micro-concrete tiles (TP0). Those tiles have a porosity that is below 1% and are practically impervious even after breaking impact tests. Rai et al. (2012) prepared 48 number of concrete mixes in which sand was partially replaced by waste plastic flakes in varying percentages by volume without and with super-plasticisers. The cube samples were subjected to compressive strength tests at three, seven, and twenty-eight days and also. Eight beams were also cast to study the flexural strength characteristic. The mix was with low workability but the addition of super-plasticizer balanced it. They concluded that reduced slump values of waste plastic concrete mixes can be used only in situations that required low-degree workability e.g., recast bricks, partition wall panels, canal linings, etc. The workability increased with addition of super-plasticizer by about 10 to 15%. However, they reported that the compressive strength decreases with increasing waste plastic ratios attributed to the decrease in the adhesive strength between the waste plastic and the cement paste.

Case study reported by Nivetha et al. (2016) aimed to study the possibility of using plastic waste of Polyethylene terephthalate as a binding material instead of cement in the manufacturing of paver blocks. The plastic waste was melted and mixed with a varying proportion of solid waste fly ash and quarry dust (PET 25-35 % fly ash 25 % and quarry dust 40-50% in weight). The measurements of physical and mechanical properties show that plastic waste paver blocks and these proportion in plastic give's better results than concrete paver blocks. Based on the experimental Investigation it was found that the proportion PET- 30%, Fly-ash-25% and Quarry dust 45 % gives maximum strength.

Agyeman et al. (2019) explored the potential of using plastic waste as a binding material for paving blocks production. They produced standard concrete paving blocks with a proportion of 'cement: quarry dust: sand = 1:1:2' by weight or volume to be used as datum for testing. They also prepared composite paving blocks less in plastic (LP) on a mix ratio of 'plastic: quarry dust: sand' =1:1:2 and high in plastic (HP) on a mix ratio of 1:0.5:1 by weight or volume by replacing plastic by cement. All the blocks were produced and tested for compressive strength at 7, 14, and 21 days curing via water sprinkling and water absorption test were done after the 72 -h of soaking. The results after 21 days indicated that paving blocks in HP and LP having compressive strengths of 8.53 N/mm2 (water absorption = 0.5%) and 7.31 N/mm2 (water absorption = 2.7%) respectively were higher than the datum of traditional Control value at 6.07 N/mm2 (water absorption = 4.9%). The authors recommended that the paving blocks made from the recycled plastic waste should be used in non-traffic areas such as walkways, footpaths, pedestrian plazas, landscapes, monument premises and in water logging areas.

Maunahan and Adeba (2021) created and tested hollow concrete blocks (HCB) by replacing cement with plastic mixing with sand, and optionally fine aggregates with water. The hollow blocks using waste plastic material in the ratio of 1:2, 1:3, 1:4, and 1:5 of hollow block size 40cm X 20cm X 10cm of different Polyethylene Terephthalate (PET) and High-Density Polyethylene (HDPE) waste plastic and sand content. The plastic was shredded, washed, dried, and melted within the range of 257-315°C temperature in open-air. After melting of PET and HDPE into liquid-state the sand material was mixed in it and fed into the mould. The tests were conducted after 48 hours. It was concluded that the blocks satisfy the class-B based on Ethiopian Building Code Standard requirements. A study published by Ghimire et al. (2021) stress the importance of mixing plastic waste in manufacturing of pervious pavement blocks that allow infiltration of storm water through the ground surface into the soil. They used High Density Polyethylene (HDPE) waste in the form of chips added to preheated aggregate ranging between 4.75 mm to 10 mm size at temperature of 190 degrees celcius. The Mix proportions of plastic were varied from 15% to 30% and aggregate from 85% to 70% by weight and standard size of cube (15cm*15cm*15cm) were prepared. They found that the optimum percentage of plastic was 23.8% for the compressive strength 4.98N/mm2 with optimum porosity 14.5%. They further concluded that the strength of plastic based previous concrete is less than the strength of cement based concrete. PhD Thesis by Thiam (2021) had a key objective of research was to investigate the engineering properties of developed mortar with plastic binder (MPB) and Plastic Waste Crete (PWC) by using molten HDPE and LDPE plastic wastes as the only binder. The plastic contents of 45%, 50%, 60% and 65% and HDPE to LDPE ratios of 40/60, 50/50, and 60/40 were selected for the experimental tests. Various tests were performed on prepared MPB and PWC samples at different curing times. These tests were conducted in accordance with the ASTM standards to evaluate the mechanical properties (compressive strength and splitting tensile strength), permeability and density of the MPB and PWC materials. Additionally the tests were carried out to analyze the products at the microstructural level (optical microscope, SEM, MIP and thermos-gravimetric analysis) to gain an insight into the microstructural properties of the developed materials and how that affect their engineering properties. The compressive strength tests revealed the optimal plastic content for the MPB and PWC with the best strength performance. The average compressive strength values for various optimal formulations after 28 days were found to be in the range of 9 to 18 MPa. The splitting tensile strength for the new materials from 1 to 28 days of curing time, were found to be between 1 and 5 MPa. The average hardened density of the MPB and PWC is about 2 g/cm3, which makes them lightweight material according to RILEM classification. In addition, various absorption tests (capillary and immersion) were performed on different MPB and PWC samples, and the obtained results showed that they are porous materials having lower rate of absorption than the traditional cementitious materials (mortar, concrete). This observation was supported by the results from both MIP and SEM analyses. Finally, thermos-gravimetric analysis provided interesting details on the thermal decomposition of the new materials, with significant changes or mass loss for these products being observed only at temperatures higher than 300°C. He concluded that MPB and PWC made with melted plastic waste as the only binder have a promising potentials for use in construction.

Parera et al. (2022) carried out a literature review and found that the development of composite construction materials based on contaminated plastic and glass is best option of waste recycling instead of throwing them in the landfill. They examined the literature on the development of such materials, including technology, challenges, quality, and properties. The development of a glass/sand composite to use as a material in the commercial scale production of building materials such as roof and pavement tiles is described based on studies that are available. A study by Soni et al. (2022) also discusses about creation of floor tiles using plastic waste. Their research explored the potential of waste plastics and silica sand for developing thermoplastic composite as floor tiles. The samples were tested for water absorption, compressive strength, flexural strength, and sliding wear. The maximum compressive and flexural strength were found to be 46.20 N/mm2 and 6.24 N/mm2, respectively, with the minimum water absorption and sliding wear rate of 0.039% and 0.143 × 10– 8 kg/m, respectively. An extensive review paper by Lamba et al. (2022) summarized the developments with regard to the use of plastic waste as a constituent of construction material. Inclusion of plastic waste as a binder, aggregate, fine aggregate, modifier or substitute of cement and sand in the manufacturing of bricks, tiles, concrete and roads has been comprehensively reviewed. Also, the influence of addition of plastic waste on strength properties, water absorption, durability, etc. has been thoroughly discussed. Zainuri et al. (2022) discuss a study to calculate the potential for reducing plastic waste in nature if mass production of paving blocks. The study achieved a compressive strength value of 13.92 MPa with 60% plastic: 40% concrete sand. The conclusion of this study is the use of plastic waste for the manufacture of plastic paving blocks saves as much as 1 m3 of 225.6 kg/m3 or can reduce plastic waste by 0.098 %/m3/day and if a manufacturer produces 10 m3 in a day, then the potential for reducing plastic waste is 7.3536 tons/day.

Versatile, aesthetically pleasing, functional and inexpensive, pavers require little to no maintenance when properly manufactured and installed. Most of his concrete block pavements manufactured in India also performed satisfactorily on his, but the two main problems were the excessive surface wear of the blocks and the variation in strength of his is an occasional failure. At the same time, the world's natural resources are declining industrial waste and residential areas are increasing significantly. Sustainable development for construction involves the use of non-conventional and innovative materials, and the use of waste materials to compensate for scarcity of natural resources and find alternative ways to protect the environment. Includes recycling. (Shanmugavalli, 2017).

Disposal of plastic waste accumulated in the 21st century poses major challenges. Therefore, for the booming construction industry, it is authoritative that the system invest to encourage the use of above mentioned use of plastic waste in making components like paver blocks. (Kazi et al., 2021). This project will reduce plastic waste in a wise way. This allows you to replace these wastes by using Low Density Polyethylene [LDPE] and old demolition concrete structures to replace the traditional materials used in the construction of paving stones. (Shanmugavalli et al., 2017).

Luckily, there are several ways to recycle plastic waste and turn it into other products. High density polyethylene (HDPE) waste is used to make bags and trash cans. These materials serve as an alternative to metal trash cans and leather bags. Plastics are a major component of municipal solid waste (MSW) and are becoming an important research topic for their potential use in pavement. Paving blocks modified with plastic waste have applications in road construction and buildings. (Chavan et al., 2021).

2. LITERATURE REVIEW

The possibility of using plastic waste as a binding material instead of cement in the manufacturing of roofing tiles was reported by Konin (2011). Polypropylene waste is melted and mixed with a varying proportion of sand (variation between 0 and 80% in weight). The measurements of physical and mechanical properties indicated that the plastic waste tiles with plastic is 40%, give better results than micro-concrete tiles (TP0).

Zainuri et al. (2022) presented a study aiming to reduce the plastic waste to prepare paving blocks with plastic waste as binding material. They produced the blocks with 60% plastic: 40% concrete sand variation with a compressive strength value of 13.92 MPa. They estimated that if a manufacturer produces 10 m3 in a day, then the potential for reducing plastic waste is 7.3536 tons/day.

B. Shanmugavalli et al., 2017: B. Shanmugavalli et al. conducted a study to replace cement in pavement blocks with plastic waste in order to reduce costs in comparison to traditional concrete blocks. Taking into account India's annual production of 56, 00,000 tons of plastic waste, which decomposes slowly, the project aimed to make use of this material. Variations of quarry dust, coarse aggregate, ceramic waste, and plastic waste were used to manufacture the paving stones. After testing, it was concluded that plastic paving stones were cheaper than concrete paving stones and an effective solution for disposing of plastic waste.

D. Hemalatha, 2019: In 2019, this project was began with the aimed of creating paving stones without any use of cement, by use of low density polyethylene (LDPE) bags and debris. This process produced a plastic road surface with thermal and acoustic insulation qualities, which helped to reduce pollution and promote sustainability. This was driven by the significant mismatch between the demanded and supply of building materials and the increasing amount of plastic waste which was polluting the environment. An attempted was made to develop paver blocks used waste LDPE bags and demolition waste instead of cement. This resulted in the creation of plastic paver blocks (ppb) that had thermal and sounded insulation properties, allowing for pollution have been controlled and paving the way for sustainability. This was seen as one of the best ways to prevent the accumulation of plastic and demolition waste in society, as well as providing an alternative to removing sand from valuable riverbeds or mines. The use of plastic waste also reduced the cost factor, as it was naturally available in abundance

Dinesh Sellakutty, 2016: Dinesh Sellakutty founded that, in mountain settlements without a garbage collection infrastructure, the increasing amount of plastic waste was polluting the environment and becoming a nuisance. It was observed that in tourist destinations, the environment and air was being contaminated due to the vast amounts of plastic that was being dumped or burnt. Thus, he argued that it was important to use these waste plastics in a useful way. They discovered that, this was one of the best way to prevent the accumulation of plastic waste, which was a non-degradable pollutant. He researched on the characteristics of bricks that was made from plastic waste, high-density polyethylene (HDPE) and polyethylene (PE) bags that was cleaned and added with sand and aggregate at various percentages to obtain high strength bricks with thermal and sounded insulation properties. This method conserved the quantity of sand or clay that had have been removed from the priceless river beds or mines. Additionally, dyes was added to the mixture to achieve the desired tint, which reduced the costed factor due to the natural abundance of plastic waste.

Nivetha et al., 2016: Nivetha and team conducted a study to determine if it was possible to create paving stones without cement by using plastic waste as a binding agent. This study focused on polyethylene terephthalate-based polymers. They combined fly ash and quarry dust in different amounts with melted plastic debris (by weight 25-35 percent PET, 25 percent fly ash, 40-50 percent quarry dust). Under their observation, it was found that pavements created from plastic waste performed better than pavements produced from concrete, based on physical and mechanical property measurements.

Chavan et al., 2019: It was discovered that the objective of their venture was to diminish contamination by utilizing plastic waste to make paving stones due to the intermolecular bonds that make up plastics, and their structure preventing them from weakening. Ineffectively discarded plastic had been washing away in reservoirs, blocking waterways, coasting in reservoirs, and sullying the water. Exploiting plastic waste in solid walkways was seen as a halfway answer for natural issues. Therefore, they began shredding plastic material and liquefying it in a compartment at a temperature go of 250ºC to 260ºC, adding ocean sand in the individual extents (1:1, 1:2, and 1:3). It was clear that plastic pavement had high quality and could be utilized for explicit needs, for example, walkways and parking garages. The ideal proportion of ocean sand and plastic increased the quality of paving stones. They then proceeded to fabricate and test pavers, comparing the outcomes to solid cement pavers.

Wahab and Nwanosike 2020: This study aimed to use plastic waste as a bonding matrix instead of cement in the production of paving stones and demonstrated the need to support the construction sector with innovative technologies that are aimed at conserving natural resources and protecting the environment. It had been observed that the use of plastic waste as an additive in the production of pavements had technical and environmental implications. It had been noted that the use of paving materials made from plastic waste was becoming more commonplace, with applications in parking lots, campuses, open spaces, roads, and secondary and highways (biodegradable). This could have been beneficial in addressing environmental and environmental problems arising from indiscriminate disposal of plastic waste.

The plastic (LDPE type) was melted in a closed system at a temperature of 180-250°C and granite dust, sand and clay were mixed in various ratios (70:30, 60:40, 50:50) to form a paper pattern. The same mould was used to manufacture traditional cement pavers. Testing for flexural, compressive strength, water absorption, oven, and acid had indicated that the paving stones made from plastic additives had higher tensile strength, water absorption, corrosion resistance and heat absorption compared to stones made from cement. In addition, the plastic paving blocks.

Salvi et al., 2021: Salvi et al. had suggested that individuals to prioritize the things they do and buy, and to consider if they really need them or if they come in packaging that produces less trash. They then gathered a considerable amount of plastic waste from tourist spots, public places, etc. Subsequently, they washed high density polyethylene bags and used them as a substitute for cement to manufacture pavement blocks. It was observed that large quantities of plastic waste were available, thus significantly reducing cost factors. Furthermore, they had recommended that if one has plastic waste, they should reuse, recycle, and reduce it. In conclusion, Salvi et al. had proposed that it is necessary to be aware of one's daily choices and purchases and that reusing, recycling, and reducing plastic waste is a great way to reduce cost factors and aid the environment.

Loganayagan et al., 2021: The project had initiated a procedure to manufacture pavement block without the use of cement, utilizing low-density polyethylene waste bags and dirt instead. This was done to create a plastic pavement (PPB) with insulation and soundproof qualities, reducing pollution and making the process more sustainable. It was also an effective way to prevent the build-up of plastic and building trash, as it required less sand to be taken from a valuable mine or riverbed. To investigate the potential of plastic waste, research was conducted to develop a product that could replace cement in paving materials. The work conducted also focused on environmentally friendly paving products, and the amount of plastic trash produced brought down cost concerns. At the time, production of plastic was increasing, with an estimated 16 tons being produced per day. The problem was that it was difficult to decompose, due to the slow decomposition process. Thus, the research sought to recycle plastic waste into paving stones and analyse the properties based on the latest industrial needs. The plastic waste collected from the surrounding area was blended with M sand in the optimum ratio and used to lay paving stones. This helped to reduce the amount of plastic waste in the environment, as well as manage environmental pollution and lower overall production.

Patil et. al., 2022: A massive variety of plastic wastes had been amassed from several places which included tourist and public places and so forth. Plastic bags were collected, cleaned, and used as a substitute for cement in the production of paver blocks. It was found that a large amount of plastic waste was available and thus the cost factor came down. Understanding the importance of what was done, one listened to the items purchased and always checked to see if they needed it or if it came in a package with less waste. Plastic, a non-biodegradable material, was increasing rapidly in the municipal solid waste every day. It was crafted from hydrocarbons found in different sources like oil, coal and some other minerals. When needed, plastic was found to be very useful but after its use, it was thrown away, creating all sorts of risks. Plastic had many different types which included high density poly-ethylene (HDPE), low density polyethylene (LDPE), HD, and so on. Consequently, these waste plastics had to be properly utilised in the making of paver blocks. Plastic was mixed and delivered with the sand and aggregate at different percentages to gain high strength.

In the current experiment, LDPE is being used due to its recyclability and ease of melting. Its melting point is between 110º-150º Celsius and its resin number is 4. The plastic bag used is approximately 50 microns in thickness. (B. Shanmugavali et al., 2017).

Table I. PROPERTIES OF LDPE

S. No.	Particulars Value	Value
1.	Melting point	150° C
2.	Thermal coefficient of expansion	$100\text{-}200\text{x}10^{-6}$
3.	Density	0.917 - 0.930 g/cm^3
4.	Tensile Strength	0.20-0.940 (N/mm^2)

(B. Shanmugavali et al., 2017).

3. CONCLUSIONS

From the above review article the conclusions made could be following:

- To identify whether used plastic garbage was suitable for making paving blocks. It aimed to create affordable paver stones that were also environmentally sustainable and to raise awareness about the necessity to recycle plastic garbage.
- The goal was to save the cost of building supplies, assist in recycling plastic waste and switching to alternative building materials whenever feasible. (Salvi et al., 2021).
- The study also aimed to compare the compressive strength and durability of plastic and regular concrete paver blocks.
- Plastic trash was mostly used to replace cement as a binding agent or construction ingredient, with the aim of reducing the amount of cement and sand in concrete pavement to increase economy and durability, while also lowering the cost. Additionally, it was hoped that this would preserve the environment and help find solutions for the secure disposal of plastic garbage. (Patil et. al., 2022).

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