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A Review on the Use of Waste Thermoplastic in Civil Engineering

Amey Kakule[1], Abhijit Thavare[2], Prof. S. N. Phule[3]

UG Student, Department of Civil Engineering, SMSMPITR, Akluj, Maharashtra, India[1-2]

Asst. Professor, Department of Civil Engineering, SMSMPITR, Akluj, Maharashtra, India[3]

Abstract: Plastic materials are widely used around the globe, often without considering their effects on sustainable development. Such widespread use has led to dangerous consequences for the environment. The growing accumulation of plastic waste presents a significant environmental challenge. Addressing this issue requires innovative approaches, such as incorporating plastic waste into civil engineering construction projects, which can also offer economic benefits. Reducing plastic waste has become an urgent priority. Various methods have been developed to use plastic waste, including its application as aggregate in concrete and as a binding agent in floor tiles. These practices not only help reduce the volume of waste but also improve the properties of construction materials. This work primarily focuses on exploring the use of plastic waste in civil engineering construction. It investigates how plastic waste can be integrated into materials like concrete and floor tiles. In Europe, more than 95 percent of de-inked plastic waste is recovered in nine countries. Between 2009 and 2014, the amount of waste generated increased by approximately 1.7 million tons, but during the same period, total waste volumes decreased by 4.9 million tons, while the amount of recovered waste rose by 6.2 million tons. Despite advancements and innovations, plastic production continues to rise, often ignoring sustainable development principles, resulting in large quantities of waste ending up in oceans and landfills. The production of plastic tends to enhance flexibility and mechanical properties. Recently, the biodegradation of plastic waste has gained attention as an effective way to reduce pollution. Common methods for managing plastic waste include landfilling, incineration, recycling, and conversion into gaseous and liquid fuels..

Keywords: plastic waste, plastic tiles, recycled plastic aggregates, solid waste management.

I. INTRODUCTION

A. Introduction

The rapid pace of urbanization and the pursuit of economic gains have significantly increased the amount of plastic waste generated. Much of this waste ends up in the oceans, harming marine life, is dumped in landfills-leading to soil degradation and unpleasant odors-or is incinerated, which greatly pollutes the air. The demand for plastic continues to grow in everyday life, yet the management of plastic waste has not kept pace with this rising consumption. Plastics are found in a variety of everyday items such as shopping bags, toothpaste tubes, book covers, and packaging materials. Today, it is difficult to imagine life without plastic, as it has become deeply integrated into daily routines. The most commonly used plastics include polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS), polyurethane (PUR), and polyethylene terephthalate (PET), all of which serve to meet daily requirements in the market.
Reducing plastic waste by incorporating plastics into the construction industry is a significant step forward. There are ongoing initiatives to utilize plastic waste in various construction applications, such as replacing aggregates in concrete, and using plastics in pavements, airports, and roads. In plastic tiles, plastics can fully substitute cement, and plastics also serve as binding agents in place of traditional adhesives.

Plastics are primarily defined by their ability to be molded rather than just their chemical composition. Thermosetting plastics, which cannot be remolded or reprocessed after their initial use, become brittle below their glass transition temperature but turn elastic when heated above it. These plastics can replace fine sand in construction. While increasing plastic content may reduce compression and shear strength, it enhances ductility. Using thermosetting plastics in concrete helps achieve strong, rigid molecular bonds through cross-linking, resulting in improved mechanical properties suitable for construction.

Globally, plastic materials are used extensively without much consideration for sustainable development, leading to hazardous environmental impacts. Polyethylene terephthalate (PET), widely used for food packaging, is a major contributor to plastic pollution. The rate at which plastic is recycled lags far behind the production of new plastics. Reducing plastic use and advancing technologies for reusing plastic are essential strategies for managing plastic waste more effectively.

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Constructing a house using plastic bottles for walls, joist roofs, and concrete columns can reduce overall costs by 45%. The molecular structure of thermoplastics greatly affects their thermal properties. Key phase transitions in thermoplastic resins include the glass transition, melting of crystalline regions, and thermal degradation of macromolecular chains. Physical characteristics such as specific volume, heat capacity, and thermal and heat conductivity are all influenced by the material's temperature. Researchers at the University of California have developed a new technique to break down polymethyl acrylamide (PMMA) within polyvinyl chloride (PVC), utilizing a process similar to those used for recycling paper and plastic bottles.

II. PRODUCTION OF PLASTIC TILES

Plastic tiles are produced by combining sand with plastic waste. It is important to use well-graded sand that is free from organic impurities. The plastic waste used typically consists largely of polypropylene, which is commonly found in plastic chairs. The manufacturing process begins by cutting and shredding the plastic waste into small pieces, which are then melted at temperatures between 150 and 170°C. Once the plastic has melted, sand is gradually added to the same container, and the mixture is stirred continuously. The sand should be introduced in small amounts to ensure proper mixing. When the blend becomes uniform, it is poured into a pre-oiled mold of a specific size, such as 30 x 30 x 2.5 cm. Oiling the mold helps prevent sticking during removal. After the mixture has cooled and solidified, the tile can be removed from the mold either by letting it air cool or by immersing it in water.

LDPE (low-density polyethylene) is a thermoplastic polymer derived from ethylene monomers and is commonly used in everyday products because of its adaptability. However, after use, LDPE items are often discarded in landfills, contributing to environmental pollution. Incorporating recyclable LDPE waste into tile production offers an effective way to mitigate the pollution associated with this type of plastic. Thermoplastics like LDPE have relatively low melting points, making them easy to recycle or reshape with heat, whereas thermosetting plastics have much higher melting points and cannot be easily remolded. In daily applications, thermoplastics account for about 80% of all plastics, while thermosetting plastics make up the remaining 20%.

Two scenarios were evaluated for using LDPE in tile manufacturing. In the first scenario, packaging plastics labeled as LDPE were collected, and any contaminants such as paper or wood were manually removed. The plastic waste was then cut into small pieces using scissors. In the second scenario, LDPE plastics were sourced from dumpsites, including items like plastic bottles and food wrappers. These plastics were sorted and washed with soap before being shredded. The processed plastic pieces were placed into molds and heated using an electric heater. Once the plastic became sufficiently soft, it was shaped as needed.

In another approach, LDPE was mixed with sand in varying ratios-1:1, 1:2, 1:3, and 1:4-and heated at 160°C until a slurry formed, after which sand was added. The resulting homogeneous mixture was allowed to cool for 24 hours. Compression tests were then conducted: in the first scenario, testing according to ASTM D 695-2015 yielded a compressive strength of 17.26 MPa. In the sand-mixed scenario, compressive strength varied with the ratio, with a maximum value of 1.787 N/mm² at a 1:3 plastic-to-sand ratio. These results indicate that LDPE can be effectively used in tile production, with several properties surpassing those of conventional tiles, suggesting that LDPE-based tiles could eventually replace traditional options.

The procedure, in this case, involves different steps. Firstly, plastic was collected, and all unwanted materials like bottle caps, skin were removed. Then waste plastic materials were chopped into small pieces. After removing the unwanted things in the plastic, the plastic waste was washed out. Then all the plastic waste was put into the pot and then melted at different temperatures like 170°, 155°, 120° and 60°C. After thawing, the pouring of molten plastic into moulds includes an uncontrolled and controlled cooling method. In the wild cooling method, the molten plastic was allowed to cool at room temperature. Still, in the controlled mode, molten plastic was poured into the forms and then pressed and covered with the thick metal sheet to delay the thermal equilibrium.

In the first case, the test on water absorption was done according to the Indian standards, but in the second case, the water absorption test was carried out using ASTM D570. Regular cement tiles used commonly in India have high water absorption capacity, which deteriorates the strength property, and in aluminum tiles, there is no water absorption. But in the case of plastic tiles, there is low water absorption capacity, which makes it optimum for use in the case where much standing water. The transverse strength increases when plastic waste increases and performs better than standard tiles when the waste plastic is 60 percent. In other cases, the power of plastic tiles without sand in between is significantly less than the aluminum tiles.

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III. PLASTIC RECYCLING

Historically, recycling in the polymers market was handled as part of the routine production process within manufacturing businesses. For example, in extrusion, material and heat are frequently combined. In-house scrap will be treated if contamination limits are allowed to improve final material manufacturing with virgin material generates Commercial and post-consumer plastic garbage is accumulating to the landfill. Consequently, the "divert from landfill" strategy encourages greater rates of recovery and recycling, even for waste types that have not previously been recycled. An analysis of waste production between 2006 and 2014 shows a slight upward trend. Lightweight plastic items, such as bottles, significantly contribute to this trend, alongside economic factors. Between 2009 and 2014, waste generation rose by approximately 1.7 million tons. However, over the eight-year period examined, total waste volumes decreased by 4.9 million tons, while the amount of recovered waste grew by 6.2 million tons, reaching up to 17.9 million tons.

IV. SUSTAINABLE DEVELOPMENT

Constructing houses from recycled plastic bottles-an emerging trend among researchers and environmental advocates-offers a sustainable alternative that preserves future resources and reduces environmental impact. These "bottle houses" are typically designed using bioclimatic principles, which help maintain optimal indoor temperatures by replacing conventional tin bricks with plastic bottles. This substitution not only reduces the demand for cement, thereby lowering CO_2 emissions, but also supports innovative recycling efforts. In the broader context of plastics, standard polymers such as polyolefins dominate the market, with polyethylene accounting for 34% and polypropylene for 24% of total usage. Engineering plastics, though a smaller market segment at about 10% of global plastic consumption, are crucial for specialized applications, while high-performance polymers cater to the most demanding requirements. Asia, led by China, is responsible for over 49% of global plastic production, with Europe and NAFTA each contributing around 18-19%. In recent years, China has rapidly become the world’s largest plastics producer, while other regions have seen their market share decline. In 2015, global plastic production grew by 3.4% compared to the previous year, with polyolefins remaining the most in-demand plastic materials, followed by PVC as the second most common resin type. Overall, standard plastics-including polyolefins, PVC, polystyrene (PS), expanded polystyrene (EPS), and polyethylene terephthalate (PET)-make up about 85% of total plastic demand worldwide.

V. RESULT AND DISCUSSION

Oluwarotimi et al. found that substituting fine aggregate in concrete with HIPS and LDPE achieved a strength of 2×10^4 kN/m², but also resulted in a noticeable reduction in both the density and workability of the concrete. Combining LDPE and HIPS may help reach the desired strength, but beyond a certain threshold, there is a significant decline in strength and other essential properties. Replacing conventional binding materials with waste plastic and quarry dust can also present challenges, particularly regarding heat resistance and load-bearing capacity . According to P. Ganesh Prabhu, PET is considered one of the most problematic thermoplastics within the polyester family . While humans have long utilized natural polymers, the demand for plastics continues to rise rapidly across various industries. Driven by convenience and advancements in research and development, plastic production has increased dramatically, often overlooking the "Principle of Sustainable Development." This surge has led to massive amounts of plastic waste accumulating in oceans and landfills. Plastics are typically valued for their flexibility and mechanical properties, and those with higher flexibility and durability tend to have longer service lives and are more likely to be recycled multiple times.

The production and use of plastics have a direct effect on waste generation, with engineering plastics being used less frequently and posing lower environmental toxicity. In 2013, global plastic production reached 299 million tonnes, marking a 3.9% increase from the previous year. By 2014, worldwide plastic output exceeded 300 million metric tonnes for the first time. Every day, various plastic waste items such as glucose bottles, IV sets, disposable syringes, needle sets, cannulas, and catheters are generated. Plastics are widely used in packaging, construction, electronics, electrical goods, furniture, vehicles, homes, agriculture, and numerous other industrial sectors. The unique properties of plastics make them suitable for a range of medical applications, from prosthetic devices to blood bags, and they can offer environmental and health benefits in certain contexts.

However, managing plastic waste remains a significant environmental challenge. Plastics are known for their durability and slow degradation, which leads to persistent waste in the environment. The extensive use of plastics in agriculture, industry, transportation, and packaging over recent decades has intensified issues related to plastic waste management.

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VI. CONCLUSION

The use of plastic waste in structural engineering projects requires special attention to effectively address environmental concerns while also improving the financial aspects of construction. Plastic waste is being incorporated as aggregate in concrete and serves as a binding agent in floor tiles. Integrating plastics into the construction industry is a significant step toward reducing plastic waste. Plastics can substitute for traditional aggregates in concrete and are being utilized in pavements, airports, and roads. However, plastic tiles made without sand exhibit much lower strength compared to aluminum tiles. Replacing traditional binding materials with waste plastic and quarry dust can also pose challenges, particularly regarding heat resistance and load-bearing capacity. PET is considered one of the most problematic thermoplastics within the polyester category. Despite advancements in research and development, plastic production continues to rise, often ignoring sustainable development principles, leading to large amounts of waste accumulating in oceans and landfills. The formation of plastic generally results in increased flexibility and mechanical properties. Biodegradation of plastic waste is gaining popularity as it can help reduce pollution. Common methods for managing plastic waste include landfilling, incineration, recycling, and converting waste into gaseous or liquid fuels. Effective management is necessary to better understand and implement various plastic waste strategies. This study also explored different applications of plastics, highlighting that using recyclable LDPE plastic waste in tiles offers a solution to reduce LDPE-related pollution.

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