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A Critical Review on Application of Waste Plastic as a Valuable Resource in the Construction Industry

Praveen Kumar Pandey[1], M.V. Raju[2*], D. Satyanarayana[3], M. Satish Kumar[4], K.Maria Das[5]

[1]Research Scholar, Department of Civil Engineering, Vignan's Foundation for Science Technology and Research, Deemed to be University, Guntur, Andhra Pradesh, India.
[2]Assistant Professor and Dy. Head, Department of Civil Engineering, Vignan's Foundation for Science Technology and Research, Deemed to be University, Guntur, Andhra Pradesh, India.
[3]Professor, Department of Mechanical Engineering, Vignan's Foundation for Science Technology and Research, Deemed to be University, Guntur, Andhra Pradesh, India.
[4]Professor and Head, Department of Civil Engineering, Kallam Haranadha Reddy Institute of Technology, Chowdavaram, Guntur, Andhra Pradesh, India.
[5]Assistant Professor, Department of Chemistry, School of Applied Sciences & Humanities, Vignan's Foundation for Science Technology and Research, Deemed to be University, Guntur, Andhra Pradesh, India.

(*Corresponding author: rajumv.environ@gmail.com)

Abstract: This review paper emphasizes the discussion on how soils, groundwater, land, agricultural land, freshwater, and marine ecosystems are becoming increasingly vulnerable to plastic and microplastics pollution. Microplastics are widely distributed through the breakdown of plastic products through physical or biochemical processes. While most research on plastics has been conducted from ecological, chemical, agricultural, and health perspectives, this review paper highlights the value of incorporating a civil perspective. Review ratings are based on a variety of studies and assess the amount, persistence, and degradation of plastic and microplastics in soils. The possible role that solid waste disposal facilities – particularly landfills – might play in contamination is also addressed. We look at the geotechnical design of these facilities and raise awareness of the possibility that microplastics can leach from landfills into soils and other environments. In addition, the study identifies other uses of plastic and microplastics as possible local sources, for construction materials including the use of tire chips, foundry sand, polyethylene terephthalate (PET) to improve the properties of construction materials, and dredged sediments to form engineered fills. Ultimately, the review highlights the importance of plastic waste as a source and as a tool to mitigate the impacts of plastic on civil structures and offers several research directions within this discipline to address and counteract the impacts.

Keywords: Waste Plastic, Bricks, Polyethylene Terephthalate (PET), Construction, Microplastics, Soils.

1. Introduction:

Many types of solid wastes are produced as a result of population growth, urbanization, industrialization, and rising living standards. Of these, plastics are particularly abundant and have been part of our daily lives. Plastic derives its name from the Greek term plastikos which means capable of being shaped or moulded. Plastics are obtained when monomers that can be synthetic or semi-synthetic organic (carbon-containing) compounds, mainly derived from natural gas and crude oil, are blended with inorganic compounds in a catalyst at defined parameters. Plastic is the best example of a boon-turned-bane. Though there are many technological developments we still lag to find technology that would end the life cycle of plastic. Plastic product manufacturing has reached startling heights on a worldwide scale, with an estimated yearly output of over 400 million tons and according to projections, this already significant number will more than quadruple by 2050[1]. Various sources back up this disturbing trend, including estimates of 359 million tons from the European Parliament's Policy Department for Citizens' Rights and Constitutional Affairs and 368 million tons from the Association of Plastic Manufacturers in Europe [2]. These findings underscore the considerable risk of widespread pollution across various ecosystems due to plastics and their remnants, encompassing marine, freshwater, terrestrial, and polar environments. This poses a significant threat to the global environment.

2. Classification of Plastics:

According to the Central Pollution Control Board (CPCB) annual report 2020-21, the Estimated Plastic Waste Generation in India is 34,69,780 tons per annum. According to the UNEP Report 2020.

a. Polyethylene (PE)
b. Polypropylene (PP)
   Based on its density it can be named as
   - ✓ Low-Density Polyethylene (LDPE)
   - ✓ High-Density Polyethylene (HDPE)
c. Polyvinyl chloride (PVC)
d. Polystyrene (PS)
e. Polyethylene terephthalate (PET)

Plastic waste represents 8% of the total waste generated in India [3]. Aryan, et al. [4] mentioned various plastic compositions such as polyethylene terephthalate composition is about 9 %, polyvinyl chloride is about 4%, high-density polyethylene/low-density polyethylene is about 66 %, poly propylene is about 10%, polystyrene is about 5%, and others is about 6%. Fig 1 has shown the % composition of plastic waste in India.

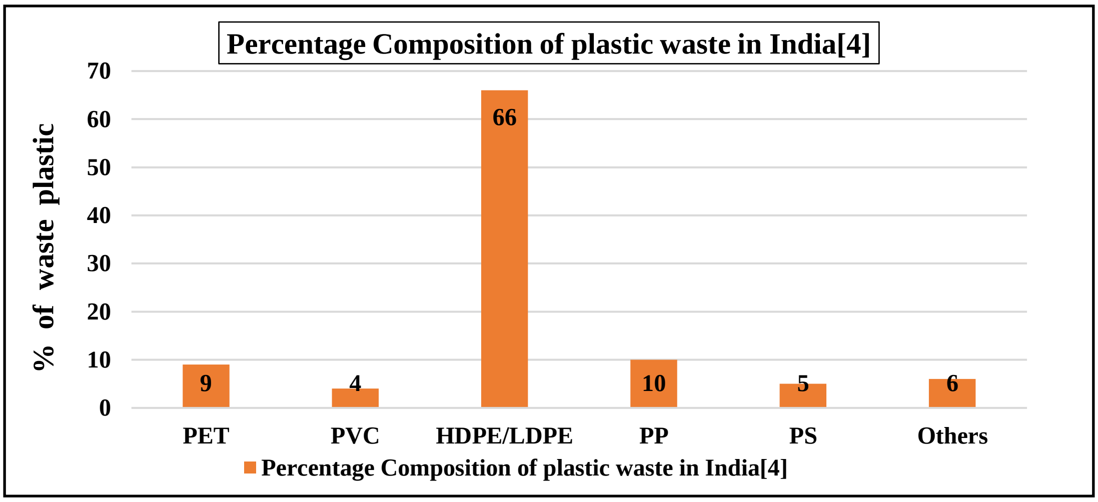

Fig. 1. % Composition of plastic waste in India.

The various percentage breakdown of plastic wastes is low-density and linear low-density polyethylene (LDPE & LLDPE)-16%, high-density polyethylene (HDPE)-13%, polypropylene (PP)-17%, polystyrene (PS)-6%, polyvinylchloride (PVC)-9%, polyethylene terephthalate (PET)-8%, polyurethane (PU) -7%, & acrylonitrile butadiene styrene (ABS)-14%, others- 4%, and additives-6% [5]. Fig 2 has shown the various % of plastic wastes.

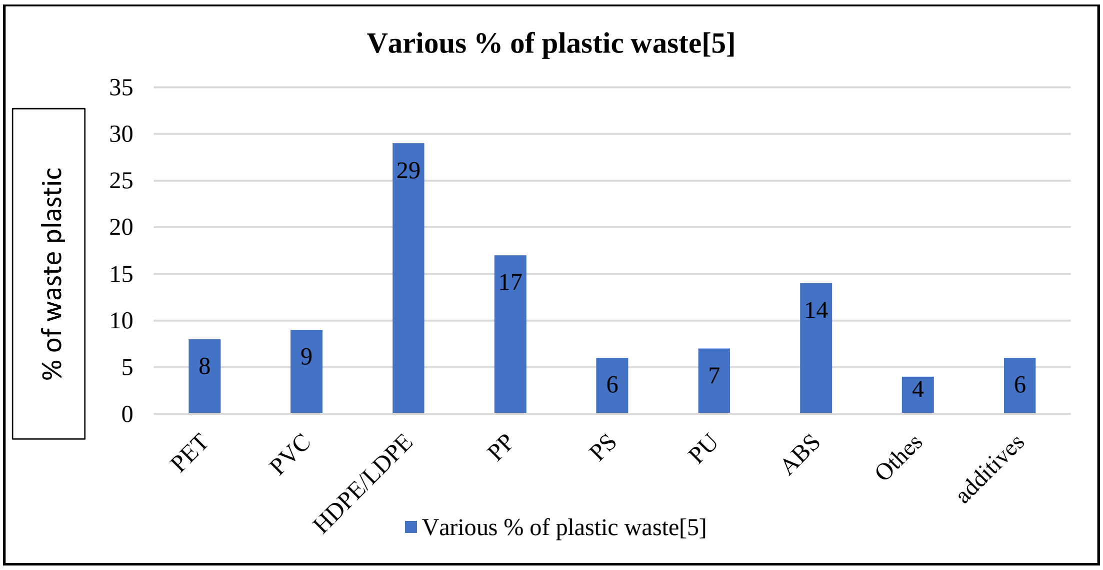

Fig. 2. Percentages of various plastic wastes

These plastic waste materials can now be added with other materials as resource materials to form a new composite material with improved characteristics. They could be admixtures in manufacturing various bricks, which were considered to be building blocks. similarly, these materials can also be added with asphalt and bitumen for laying flexible pavements, they can also be used in slope stabilization, soil stabilization, and many more applications that have to be researched. When plastic waste materials are substituted or replaced within proportions in the concrete mix, it has environmental and economic benefits.

3. Waste Plastic as Valuable Resource:

3.1. Plastic Waste as a Resource Material in Pavement:

The bituminous binder used in pavement construction work includes both bitumen and tar. Both of these binders have a similar appearance but have different characteristics but both of these binders can be used in pavement work. Bitumen is a complex organic material obtained by distillation of petroleum crude, whereas even "plastics," are derived from various fractions of crude oil through processes like cracking and polymerization. Since both of the materials are produced in the petrochemical industry they have good bonding. For bitumen, typical application temperatures range from around 150°C to 180°C (302°F to 356°F). At these temperatures, bitumen becomes sufficiently viscous for mixing and application, whereas thermoplastic materials like polyethylene and polypropylene typically soften at temperatures ranging from 100°C to 150°C (212°F to 302°F) Bhatnagar et al.[6] studied various properties of Bitumen with various percentages of PET addition and he affirmed that an important use of PET waste materials is the recycling of waste plastic into asphalt for pavement.

Bitumen asphalt mix properties such as strength, fatigue life, and other desirable features of bituminous concrete mixes have significantly improved by the addition of processed waste plastic (PET). By addition of 5–10% by weight of bitumen there is increases in pavement performance and lifespan while reduction in bitumen consumption. The procedure is not harmful to the environment and a significant amount of waste plastic is also used. When plastic is melted and mixed with aggregate it acts as a thin plastic film coating onto the aggregate thus repelling water and increasing the life span of pavement. So these procedures provide improved pavement infrastructure and are therefore very relevant to society in utilizing the waste plastic and thus saving the environment.

To withstand the tyre pressure and weather the surface of the flexible pavement should have characteristics that exhibit strength, ability to drain off surface water, and friction, soundness (wearing action of aggregates). So during the laying of flexible pavement when hot stone aggregate (170 ºC) is mixed with the hot molten bitumen(160ºc) and then mixed well before laying [7]. The bitumen is chosen based on certain properties like binding, and viscosity. When the waste plastic is mixed with aggregate (160ºc) waste plastics get melted as the melting point of PET is 245ºc to 260ºc [8] and it improves the properties like voids, and moisture absorption. The addition of Pet in the mix helps to improve the property of porosity and to improve the quality of aggregate and its performance in the flexible pavement.

3.2. Plastic Waste as a Resource Material in Paving Blocks:

Ahmad et al. [7] studied waste plastic utilization[PET] as an addition to cement-based concrete paving blocks standard concrete blocks without the replacement of PET have a compressive strength of 21.4 MPa while 5%, 10%, and 15% of PET have 20.9 MPa, 12.2 MPa, and 10.9 MPa respectively.

The strength performance for PET concrete after 7 days fluctuated with the increase of PET content; 5% PET content has increased the strength up to 49.2% as for 10% and 15% of PET content has deteriorated the performance by 21.2% and 7.8% respectively. The reduction in compressive strength with the addition of plastic content could be due to low adhesive strength between the plastic surface and the cement paste, coupled with poor morphology; additionally, since plastic is an inert material, it does not react with the cement properly. Thus, if PET is added in more than of 5%, the concrete pavement block would not become any stronger, but it can still be used for nonstructural applications.

3.3. Plastic Waste as a Resource in Other Construction Materials:

Finding materials that can lower construction costs while strengthening engineering infrastructure is a topic of great interest for researchers. The use of plastic waste for construction applications in the engineering industry holds a high capability of decreasing worldwide ecological contamination and environmental pollution. Plastic aggregates, cementitious materials, soil stabilization additives, and other construction resources obtained from plastic waste were examined by Ogundairo et al. [9] and shown that, as it comes to manufactured materials, the behavior of plastic waste in building materials is naturally special. Not yet, when compared to traditional building materials, construction materials made from plastic trash can yield results that are on par with or even superior. Using waste plastic will contribute to lowering the amount of traditional building materials needed over time, which will reduce the carbon footprint of these items' making.

3.4. Plastic Waste as a Resource in Composite Brick Production:

The topsoil is often used for brickmaking. It is well known that the topsoil is a rich source of nutrients for vegetation, this nutrient base is depleted by large-scale brick manufacturing since they are extensively used for brick making. so there should be an alternative for partial or full replacement of topsoil. potential partial replacements are polyethylene terephthalate reinforced in clayey soil [10], recycled waste of blacksmith [11], waste plastic [12], foundry sand [13]. Fig 3 has shown the classification of bricks.

Classification of bricks:

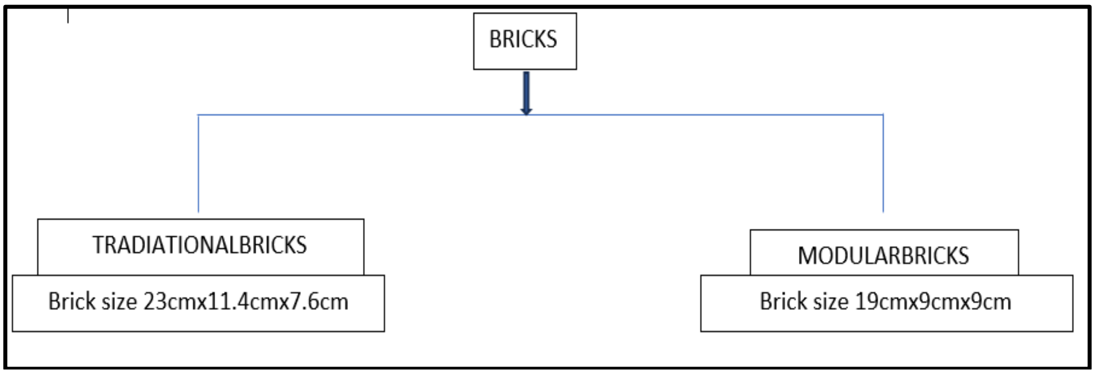

Fig. 3. Classification of bricks

Good burnt bricks, sometimes referred to as fired bricks, have several advantageous qualities that make them appropriate for use in a variety of construction applications. Burnt bricks should have sufficient compressive strength to withstand the loads experienced in construction. Typically, the compressive strength of burnt bricks according to IS 1077:1992 ranges from 3.5 N/mm^2 to 35 N/mm^2, depending on factors such as composition, manufacturing process, and firing temperature. When polyethylene terephthalate was added as a partial replacement of soil to 5% then the compressive strength of the burnt brick was found to be 3.5 N/mm^2 which does not fall under any category of IS 1077:1992 to the same it was 5.15N/mm^2 when no polyethylene terephthalate was added. so only based on compressive strength we can say that the brick is not suitable for construction various other characteristics should be studied. While samples containing over 10% PET collapsed during the firing process, samples containing less than 10% PET did not collapse but instead underwent shape deformation. When compared to

the control sample, the bricks with PET content had a lower compressive strength, however, the sample with 5% exhibited some decent results in terms of structural efficiency[8]. This suggests that bricks with 5% or less PET might function effectively, although more research is needed on this. If binder-like bitumen of 2% is added along with waste plastic, then the compressive strength of the brick is enhanced. It is evident from
Fig. 4 has shown the brick's compressive strength increases with varying percentages of plastic material [14] when 2% bitumen is added as a binder, by IS code 1077:1992.

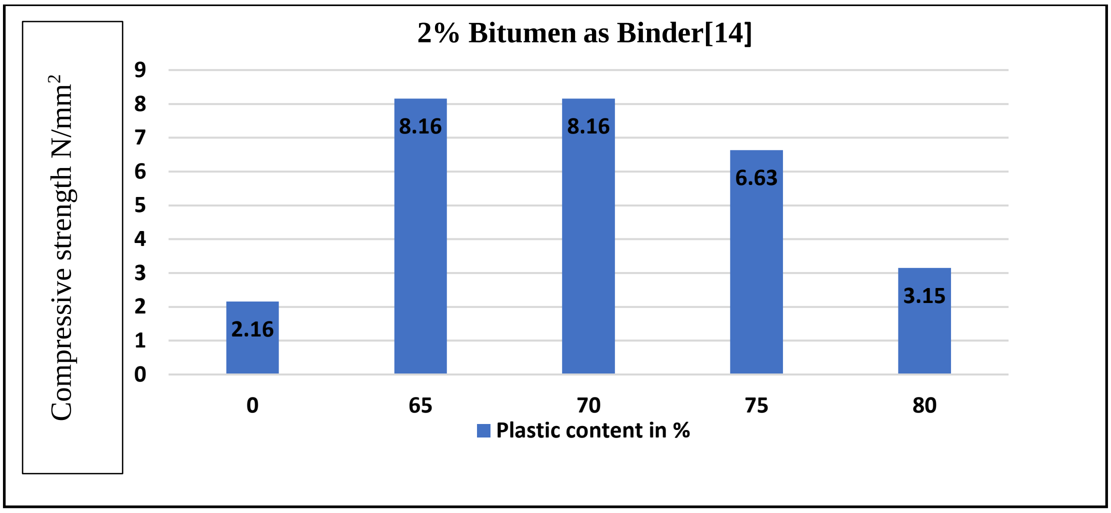

Fig 4. Compressive strength increases with varying % of plastic material

Research was done to find out how adding steel filings to the burnt clay brick mixture affected the mixture's compressive strength, density, and water absorption capacity. In order to improve building materials and conserve resources, the study also looked at the advantages of incorporating debris from blacksmiths' workshops. It is evident from Fig. 5 has shown the brick's compressive strength increases with varying percentages of debris from blacksmiths' workshops material [15] which is in accordance with IS code 1077:1992.

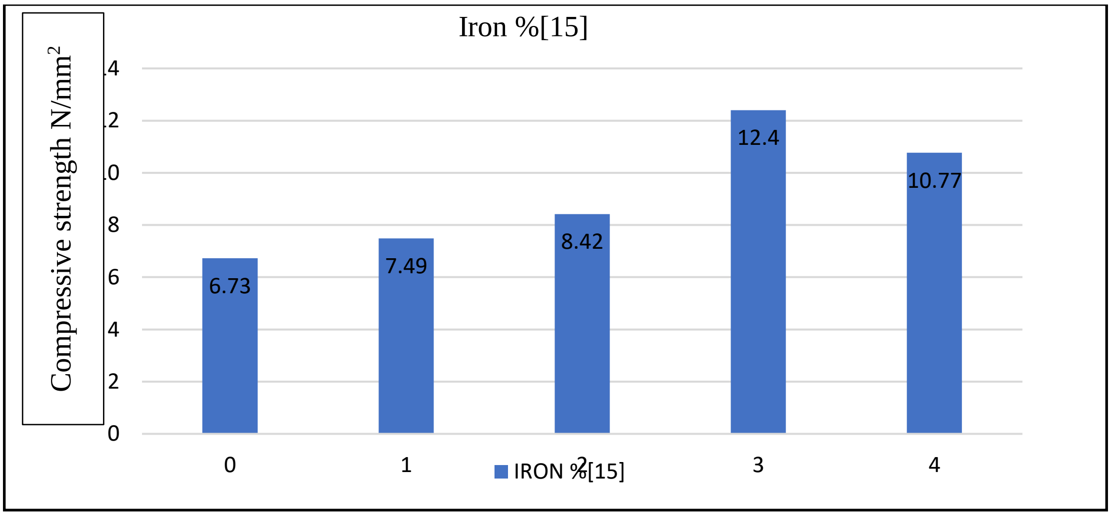

Fig. 5. % of Debris from blacksmiths workshops material

4. Environmental Impact and Applications and Future Directions:

An evaluation of the environmental effects of these materials, as opposed to conventional materials, that will be utilized in the civil engineering field, taking into account the potential for waste diversion, embodied energy, carbon footprint, monitoring the state of the environment, and other aspects that need further study.

Durability, affordability, and sustainability are just a few advantages of using waste plastic to make building materials. In order to maximize the performance of construction materials generated from waste plastic and discover new applications, research and development efforts must continue. Investigating cutting-edge production techniques, improving material qualities, in general, using waste plastic to make building materials presents viable ways to tackle sustainability issues in the construction sector, all the while advancing the ideas of the circular economy, lowering dependency on finite resources, and evaluating environmental effects over the course of a product's lifecycle.

4. Challenges and Opportunities:

Plastic waste-derived building materials have many advantages, but there are drawbacks as well as potential because recycled plastic feedstock varies in composition and properties, it can be difficult to ensure consistent quality and performance of construction materials made from it. Novel construction materials made from plastic waste may also have difficulties meeting building codes and regulatory standards, necessitating extensive testing and certification to guarantee compliance with safety and performance requirements. Due to misconceptions regarding the caliber, dependability, and visual appeal of plastic-based building materials, it can be difficult to overcome skeptics and win over stakeholders, such as architects, engineers, builders, and consumers.

5. Conclusions:

In conclusion, the building sector has a potential opportunity to innovate sustainably through the use of waste plastic to create construction materials. Through the utilisation of technological advancements, stakeholder collaboration, and increased understanding of the advantages of construction materials derived from plastic, we may surmount challenges and realise the complete potential of this burgeoning industry. Using these materials allows us to design durable, resource-efficient structures that satisfy the demands of both the present and the future, in addition to reducing the amount of plastic pollution. It is crucial that we prioritize research, make infrastructure investments, and foster an atmosphere of supportive policies that encourage innovation and adoption as we continue to investigate and improve these materials. In the end, we can create a constructed environment that is more resilient and sustainable by adopting building materials derived from waste plastic.

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