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Invited Article

Waste Plastic Management – A Step Towards Circular Economy

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ABSTRACT

Plastic, the most utilized synthesized organic material, is the product of spectacular developments in the area of polymer science and technology. The penetration and acceptance of plastics into social network has revolutionized the universe with its widespread usage to the extent that it is now difficult to imagine a life without plastics in our day-to-day life. Positive aspects of plastics have also created a negative impact in our life because plastics do not degrade and reutilizing waste plastics is a major problem. Waste plastic is mainly composed of low-density polyethylene plastic bags and other plastic scrap. Five hundred trillion bags are consumed every year in the whole world and this is just being thrown away without any proper disposal. This is the main cause of plastic pollution. Incineration of the waste plastic bags causes environmental pollution. 3 kilograms of carbon dioxide is released if 1 kilogram of plastic is burnt and that attributes to global warming. Disposal of plastic waste to dumping sites may take approximately 500 years to completely degrade. The aim of this research work is to utilize waste plastic scrap for fabricating interlock paver tiles or partition tiles which can be used as an alternative to conventional tiles. Various issues concerning plastics, like mechanical strength, flame retardancy, water permeability, UV- protection from sunlight, acid, and alkali resistance, and antistatic response have been analyzed for the purpose of the research.

Keywords: Circular economy, interlocking tiles, low-density polyethylene bags, plastic scrap, waste plastic management, waste plastic recycling

1. INTRODUCTION

If there is one type of municipal solid waste that has become ubiquitous in India and most developing countries, and is largely seen along the shores and waterways of many developed countries, it is plastic waste. Much of it is not recycled and ends up in landfills or as litter on land, in waterways, and on the surface and beds of the ocean as shown in Figure 1. Polyethylene bags contribute to most of the plastic waste in landfills. This causes major environmental hazards, as the degradation of plastic bags on exposure to UV light from sun rays leaches out various bi-products and chemicals that mix with soil and waterways and disrupt the environment balance.

Scattered plastic lying by the roads, in the sewer, and in city dumps is a common sight in India. It has been observed that every day total plastic waste generated in India amounts to 15,500 tons which means 56 lakh tons of plastic waste is generated every year. In Delhi alone, 690 tons of plastic waste is collected every day, whereas Chennai produces 429 tons of plastic waste followed by Kolkata which produces approximately 426 tons of plastic waste every day, and Mumbai where the plastic waste collected is 408 tons per day. It was informed by Pollution Control Board of India to Supreme Court that only approximately 60 percent of waste plastic is recycled and rest goes to landfill sites for dumping. It has adversely affected the flora and fauna, and has also become a cause of further deteriorating environmental conditions.

Figure 1: Waste plastic bags in landfill sites and on the banks of rivers

The Supreme Court of India has reprimanded big cities for their poor waste management. Waste plastic reutilization is a big concern in many countries as it is non-biodegradable. The waste plastic scrap comprises of low-density polyethylene bags and other analogues of poly olefins which are bio-persistent. Incineration of these polyethylene bags and other plastic containers is a major worry for environmentalists. Reutilization of waste plastic scrap into interlocking paver tiles can solve the issue of waste plastic handling. Our research on "Utilization of waste plastic to tiles designing", provides a unique method of fabricating interlocking tiles. This technology can provide employment to millions of waste plastic collectors who make efforts to gather plastic waste from households and roadsides. The collected waste plastics make their way to plastic traders and start-ups who convert these plastic scraps into granules to fabricate value-added products, thus helping protect the environment. Some specific tests like flammability test, water intake capacity and load-bearing capacity of the tiles have been carried out as described in the guidelines of American Standards and Testing Methods (ASTM).

Plastic products have become an integral part of our lives and play an irreplaceable role in our day-to-day lives. With the increasing use of plastics in different commercial applications they make up a fundamental part of our everyday lives (Andrady et al., 2009). Types of plastics that are widely used are thermoplastics and thermo-setting plastics. Among these, thermoplastics can be easily and cheaply molded and re-molded to different usable forms (Akçaözoğlu et al., 2010). Hence, a huge market exists all over the world for the thermoplastics (Thompson et al., 2009a). But the many usages of these plastics also make them a threat for the existence of life on this earth. In the present time around the cities, huge landfill sites can be seen which release a foul smell in their surrounding areas. Many animals die in the oceans and on the land when this plastic is consumed by them, choking their respiratory passage and blocking their nervous system. Chemically, these plastics are non-biodegradable and can add to ground and water pollution; these factors make their disposal a major concern (Thompson et al., 2009b; Ryan et al., 2009).

Advancement in science and technology around the world has led to better lifestyle, leading to a rise in the GDP of the countries. The more utilization of plastics in day-to-day lives has given an additional burden to the solid municipal garbage, leading to increased heights of dumping sites (Shaxson, 2009; Shent et al., 1999). Out of the entire plastic waste generated worldwide every year, two-thirds accounts for a class of polymers belonging to polyalkane chains such as polyethylene (PE), high-density polyethylene (HDPE) and polypropylene (PP), and the remaining 22% belongs to thermosetting polymers like epoxy resins, polyurethane, etc. (Al Salem et al., 2009). The major difference between the two broad classes of plastics lies in the manner they respond to temperature changes. Thermoplastics melt and soften with the increase in temperature whereas the thermosets polymerize and become stiffer on increasing temperature. Thermoplastics can further be differentiated on the basis of their chemical structure and morphology. Thermoplastic polymers can show both amorphous and crystalline morphologies. The thermoplastics with randomly arranged polymeric chains, like polystyrene (PS) and polyvinyl chloride (PVC), exhibit amorphous structure whereas polymers with ordered molecular arrangement form crystalline structure with varying degrees of crystallinity that governs the physical and mechanical properties of the polymer structure. Another class of plastics that has emerged in the past decade is engineering plastics, which has found its application as a substitute for metals in small devices and structures with adequate physical and mechanical properties. They have many advantages like low processing cost, resistance to different chemicals and corrosion, low density, and ease of processability. Although plastics do not have any superior properties in comparison to other materials but the favorable balance of different properties and relative ease of getting molded into complex shapes make them a popular choice in comparison to other engineered materials.

Among the different types of plastics available, thermoplastics are considered suitable for the fabrication of composites as they can undergo repeated melting processes whereas thermosetting plastics can undergo only a single processing cycle and become irreversible solids post initial increase in temperature. Also, thermoplastics blend with different fillers with a lot of ease in extruders followed by molding (injection or extrusion) of the composite in order to obtain the final product. Of the total waste collected worldwide, one-third of the waste is composed of polyethylene bags, pouches, wrapping materials etc. (Masuda et al., 2001). Polyethylene bags are used in all industrial and household sectors such as electronics, construction, waste collection bags and different types of pipes (Angyal et al., 2007; Shah et al., 2008; Pramila & Ramesh, 2017). The waste belonging to poly polyethylene family forms a major junk of municipal corporations and generally goes to landfill sites for dumping (Guerrero et al., 2013). In the absence of proper guidelines from the Government for its disposal, these polyethylene bags become a major source of plastic pollution causing blockage to the drainage system and thereby causing huge problems to the society (Lithner et al., 2011).

The ethylene units present in the polyethylene take a longer time to degrade creating a major junk of solid municipal waste (Ryan et al., 2009; Browne et al., 2008; Oehlmann et al., 2009). At present, either this waste is sent to industrial units for burning or it simply goes to the landfill sites. This leads to increased levels of pollution in the air. Transporting waste to landfill dumping sites involves a large amount of expenditure (Jambeck et al., 2015). Hence, recycling plastic can solve the problems of waste plastic menace (Masuda et al., 2001; Zia et al., 2007). Plastic recycling can be defined as a process to convert plastic scrap into various useful products. The recycling process is an attempt to clean the environment, to save the lives of living beings, and is also a business proposition (Hamad et al., 2013; Singh et al., 2017; Hopewell et al., 2009).

In the last decade, research and development have been more focused on designing newer methods of recycling and proper usage of waste plastic in fabricating value-added products with superior properties. Butler et al. (2011) studied the current state-of-the-art method and provided a detailed review of the commercial production of poly olefins to oil. Literature reports work done by researchers to break down the polymer chain into monomeric units and oligomeric units from the waste plastic using controlled pyrolysis techniques (Ray & Thorpe, 2007; Sharma et al., 2014). Various research institutes and universities have designed methods to fabricate waste plastic-based fine aggregates as fillers in concrete to reinforce the mechanical and chemical durability of conventional concrete (Saikia & Brito, 2012; Ismail & Al-Hashmi, 2008; Bhogayata & Arora, 2008). In addition to this, a lot of work has been done to utilize waste plastic bags in road carpeting. The waste plastic along with bitumen can lead to the laying of roads having superior strength and better resistance to water. Interestingly, the Ministry of Road and Transport has made guidelines for the usage of waste plastic in the making of roads (Huang et al., 2007). Many researchers have developed techniques for converting waste plastic to graphene, multi-walled carbon nanotubes and carbon dots (Bazargan & Mckay, 2012; Gong et al., 2013).

As per the latest data from the Ministry of Environment & Forest, unscientific recycling of plastic waste is creating humungous pollution. Though the Government has banned the import of plastic waste from developed countries, still under some pretext, waste plastic is getting imported. Hence, adopting a proper scientific method of recycling plastic waste is the need of the hour. The research work carried out by our team in fabricating interlocking tiles from waste plastic can provide an impeccable solution to this worldwide nuisance. Cement and concrete have been prevalently used as construction materials for decades. However, an alternative approach is needed to design structures that have more flexibility, are lightweight, and have resistance to corrosion. Hence, interlocking plastic tiles can be considered an ideal substitute for concrete paver tiles or cement floor tiles. By using tiles made from waste plastic, we can save our raw material resources like sand, cement, and stones. Waste plastic tiles blended with fly ash (a source of silica) can provide better service life to the building structures and more resistance to acids and alkalis. Plastic tiles being lightweight and flexible can be easily used in complex designs. Nowadays, wood plastic blends are being used in many construction sites because of better durability, low cost of repair, and flexibility in designing final structures.

The main aim of our research is to reutilize waste plastic scrap for designing interlock tiles[1]. The various facets like mechanical strength, flame retardancy, water permeability, UV protection from sunlight, acid and alkali resistance, and antistatic response are the novelty of the technology.

1.1. Benefits of technology

The present research work focuses on a unique method of fabricating tiles from waste plastic scrap. Reutilization of polyethylene scrap in designing interlocking tiles with better shelf life and better skid resistance provides a commercial solution for plastic scrap disposal. Thus, our research and development work provide better earning opportunities for waste collectors and at the same time is an initiative to clean the surroundings. We are of the opinion that banning or burning plastic scrap in the dump yard is not the only solution. Polyethylene bags thrown in the streets or roadsides are eaten away by roaming cows and other animals and these get struck in their digestive system leading to the death of these animals. Even sea animals are trapped in the nylon traps and other plastic scraps leading to their death. In rainy seasons, our wastewater pipes get blocked leading to flooding of roads. Incineration of polyethylene scrap in open air leads to global pollution. We propose a better solution for waste plastic management and scientific recycling of waste plastic utilization. These interlocking tiles designed by our group can be easily placed on the pavements or as floor tiles or partition tiles in homes or buildings. Some specific tests like the flammability test, water retention, and load-bearing strength of the tiles have been carried out as per ASTM standards. Other parameters, like, environmental stability, resistance against strong acids, and strong bases are also successfully tested.

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1.2. Market potential

The plastic recycling market is huge and is growing tremendously across the globe. The need of the hour is to prevent the recyclable plastic waste material from going to the plastic processing and disposal sites and using up landfill space. Salvaging it at a source for recycling could make profitable use of such material. Currently, a very small percentage of unutilized plastics is recycled, whereas the potential is much higher. As plastic consumption is expected to grow in the coming years, the market for recycled plastic products will witness huge growth.

2. TYPES AND PROPERTIES OF FILLERS ADDED IN THE POLYMER MATRIX

2.1. Waste by-product from coal thermal plant

An estimated 0.6 hectare per MW of electricity is generated from coal thermal plant. Coal ash particles obtained from coal thermal power plants are a major threat to the environment and the management of fly ash is a matter of concern in these plants. At present, more than 150 million tons of coal fly ash is produced from 120 existing coal-based thermal power plants in India. With the present practice of fly-ash disposal in ash ponds (generally in the form of slurry), the total land required for ash disposal would be more than 90,000 hectares by the year 2024. Handling of fly ash is a major problem as the finely divided particles present in coal ash are the leading source of air pollution. It causes many respiratory diseases and is a matter of concern in the health sector.

2.2. Physical properties of coal ash

The size of the coal ash particles ranges from 50 to 100 microns and it exhibits spherical morphology as observed from scanning electron micrograph. The color of the fly-ash ranges from dark grey to brownish grey due to the presence of ferric oxide and other oxides. These ash particles which are a rich source of silica and aluminum oxide can be used in various industrial sectors, ranging from cement industries to brick-making industries. The physical properties of coal ash particles are given in Table 1.

Table 1: Basic Characteristics of coal ash

Structure	**Free flowing powder**
Shape	Circular
Nature	Amorphous
Particle Size	50 to 100 microns
Bulk Density	1.0-2.5 g/cm^3
Specific Gravity	2.1 to 3.0
Specific surface area	300 to 400 m^2/kg
Colour	Dark grey to brownish gray

2.3. Chemical properties of coal ash

The chemical analysis of coal ash by X-ray fluorescence and other spectrometric techniques states that it is basically a ferroaluminosilicate material having Aluminum (Al), Silicon (Si), Calcium (Ca), Magnesium (Mg), Iron (Fe) and sodium (Na) being present in their oxide form. Besides these, some toxic metals like Lead (Pb), Arsenic (As), Mercury (Hg), Chromium

(Cr), Nickel (Ni) and Zinc (Zn) are also present in coal ash. The X-ray diffraction (XRD) analysis of coal ash reveals the presence of different crystallite phases like quartz, magnetite, hematite, mullite, anorthite and other minerals.

2.4. Disposal and utilization of coal ash

The coal ash generated from coal thermal power plants is gathered in big ponds filled with water and is kept for further utilization by other industries like cement industries and brick making sector. Coal ash poses a serious threat to the environment because the particles are submicron in size and increase the level of air pollution by increasing the levels of PM 2.5 and PM 10. Fine silica and aluminum oxide particles present in coal ash can be further utilized in designing geo polymers which can be used as an alternative to cement. Many developing and developed countries in the world are now using fly ash in cement and for making geo polymers. Besides the use of fly ash in cement industries, coal ash has also found usage in the agriculture sector, ceramic industry, and coal ash bricks. In our research studies, we observed that fly ash blended with coal ash provides better combustion retardance properties when incorporated with suitable compatibilizers.

3. METHODOLOGY AND CHARACTERIZATION

3.1. Methodology

The process involved in the fabrication of composite tiles from waste plastic initially requires the selection of a type of thermoplastic that could be used as a matrix for reinforcing any of the above fillers. The selection of the plastic to be reinforced might appear to be difficult but requires a general awareness of the behavior of a particular type of plastic as a group and its characteristics as an individual plastic. The initial and utmost important step in designing the composite is defining its purpose and end application of the proposed product. Identifying and studying the service environment are other steps to be taken care of. The next step lies in assessing the suitability of different plastics based on their characteristics for most engineering components. A wide variety of plastic waste is generated, but our aim is to put to use different types of easily recyclable thermoplastics. The reason is that they are easy to process and do not add toxic pollutants to the environment. Low-density polyethylene, high-density polyethylene, and polypropylene are considered for processing. The choice of waste plastic to be reinforced greatly influences the nature of the application, the cost of production, and the service environment. The plastic wastes are reinforced with fillers to enhance their physical, chemical, and mechanical properties. Mostly, conventional processing techniques are used to produce molded articles. For applications that require semi-finished products like sheets and rods for the fabrication of structures, conventional methods like welding or machining can be used. Many applications require finished products that are quite complex in structure and shape like producing a pipe by extrusion or a telephone housing by injection molding. These are produced in a single operation which involves continuous processing stages of heating, molding, and cooling or a repeated cycle of events. Since there is a wide range of processing techniques available for plastics, it is important to have a basic understanding of the design process and processing methods as the wrong selection can further limit the choice of molding method.

The fabrication of waste plastic composite tiles involved two different molding techniques i.e., extrusion followed by compression molding. In the first step, discarded plastic bags were first collected, segregated, and then cleaned for further processing. After the completion of the first step, the cleaned plastic waste was dried and then shredded into smaller pieces. This was followed by mixing with different filler materials as per the formulated composition. The third step involved the extrusion of the prepared composition in the form of wires using a single screw extruder. The extruded composite wires were cut into pellets that were then used for different applications. Finally, in the last step, the pellets thus obtained were heated in an oven for 30 minutes at 150°-180°C and were then molded into the tile of the desired shape using compression or injection molding technique. Figure 2 gives the schematic representation of the process of fabrication of composite tiles.

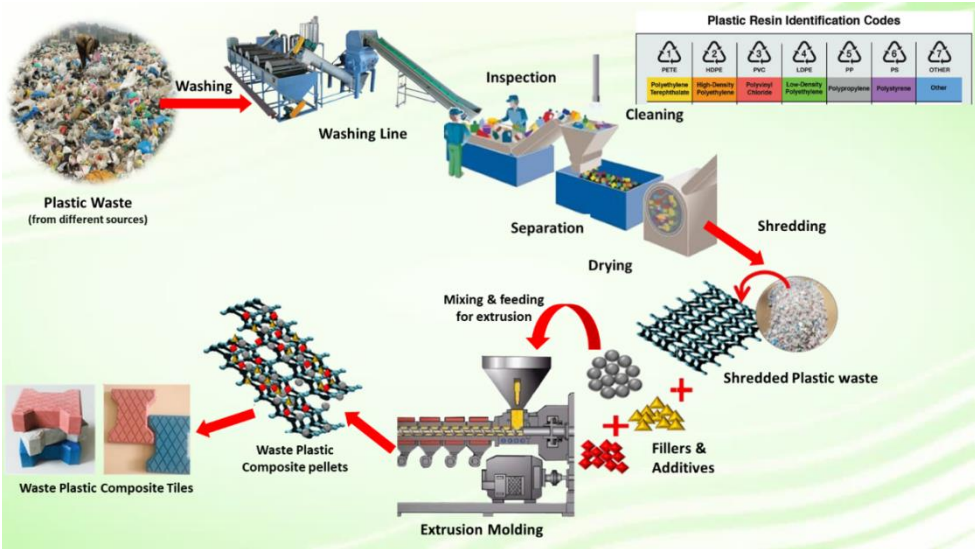

Figure 2: Schematic representation for fabrication of composite tiles

3.2. Characterization of waste plastic composite tiles

3.2.1. Gas analyzer test

The process involved in the fabrication of tiles required heating of plastic waste at 140-150°C in order to melt the pellets for homogeneous mixing and molding purpose. The evolution of gases during this process has drawn attention and raised concerns. The amount of gases released during the entire fabrication process was measured using the flue gas analyzer. For the testing, a heating setup was arranged and connected to the chimney. The plastic tile was put in this setup and heated to the temperature of 160-180°C, the other end of the chimney was connected to the flue gas analyzer. The gases like carbon dioxide (CO_2), carbon monoxide (CO), sulphur oxides (SOx), nitrous oxides (NOx), and volatile organic compounds (VOCs) evolved during the melting process of waste plastic tile were analyzed using a standard Gas analyzer under ambient temperature conditions. The gases released during the process were analyzed for 30 minutes at ambient pressure and the mean of all gases was taken at equal intervals of 30 minutes to give an average concentration of gases evolved. The average and exact values of the concentration of different flue gases released during the process were reported after repeating the process three times. The values obtained are tabulated in Table 2.

Table 2: Concentration of gases evolved from composite tiles

Gases	**Amount evolved**
CO_2	0.5 %
CO	5 ppm
NOx	No evolution
SOx	No evolution
VOCs	No evolution

3.2.2. British pendulum test

The paver tiles fabricated under this innovation can be put to use at external walkways, parks, footpaths, elevator lobbies, and pedestrian crossings. To ensure their application, skid resistance was analyzed using the national standard method British Pendulum Skid Resistance Tester (ASTM E303- 93) as depicted in Figure 3. This technique helps in studying the surface frictional properties of these tiles in both dry and wet conditions and also with changes in temperature. This technique gives us the value in British Pendulum Number (BPN) which is the measure of friction between the rubber slider and the tile surface. The friction between the surface and slider is directly proportional to the skid resistance. As the value of surface friction increases, skid resistance increases and also the value of BPN. During the measurement, the pendulum with rubber slider is allowed to perpendicularly swing over the tile's surface and the scale gives the value of BPN as shown in Figure 3.

Figure 3: Skid resistance of composite tile by British Pendulum Tester

For the precise measurement and accurate results, the mean value of BPN was reported after repeating the process three times. The process was performed for both dry and wet conditions in a similar manner, but with a precaution that the surface of the composite tile is wetted each time before taking the values for BPN in wet conditions. The mean values of BPN for dry and wet conditions of the composite tiles are given in Table 3.

Table 3: Mean values of the British Pendulum Test of paver tiles under dry and wet conditions

S.No.	Skid Resistance (Skid Number, SN) Dry	Skid Resistance (Skid Number) Wet	Dry/Wet
1	100	50	4.6
2	101	50	7.3
3	99	51	8.0

4. APPLICATIONS

The decorative colored tiles can be used in a variety of applications as shown in Figures 4 and 5. The application of these tiles in day-to-day life includes making structures of rooms or toilets, deck floors, interlock tiles for pavements, roof tiles, railings, fences, landscaping, horticulture, and wall decoration, building exteriors like wall cladding and siding, park benches, molding and trim, window and door frames, indoor and garden furniture, waterproof, durable floor tiles and floor coverings, colorful bricks and blocks to divide up rooms or outdoor areas.

Figure 4: Interlock floor tiles and paver tiles made from waste plastic

Figure 5: Tiles from waste plastic installed by Municipal Corporation, Hyderabad

5. CONCLUSION

The process involved in designing of composite tiles lays down an innovative approach for recycling waste plastic material in our daily life and industry in an environmentally stable and economically viable manner. The designed products are light in weight, resistant to corrosion, chemicals and UV-rays, have low production cost, increased serviced life, and most importantly have put to use plastic waste which has become a menace for society. Also, these fabricated tiles can be considered as a replacement to conventional cement tiles as they are unbreakable, have improved mechanical strength, and have a better service life.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Annexure-I

The technology has received Smart Fifty Innovation Award in 2018 which was given by DST & IIM Kolkata

Visit of Dr. Jitendra Singh, Hon'ble Minister of State for S & T, Earth Sciences and Dr. Shekhar C. Mande, DG-CSIR on January 4, 2022 on the occasion of NPL Open Day

(a) Tiles installed at Sector 15, Bandh Area, Gurugram. (b) Anand Mahindra has recently tweeted about these tile