JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Utilization of Waste Plastic in Highway, Construction and Medical Industry: A Review

[1]Dr. Sindhu J. Nair, [2]Prachi Rai
[1]Professor, [2]PG Scholar
[1,2]Department of Environment Science and Engineering, BIT Durg, India.

Abstract: The exponential rise in the production of plastic and the consequential surge in plastic waste have led the scientists and researchers look out for innovative and sustainable means to reuse/recycle the plastic waste in order to reduce its negative impact on environment. Construction material, converting waste plastic into fuel, household goods, fabric and clothing are some of the sectors where waste plastic is emerging as a viable option. Out of these, construction material modified with plastic waste has garnered lot of attention. Modification of construction material with plastic waste serves a dual purpose. It reduces the amount of plastic waste going to landfills or litter and secondly lessens the use of mined construction materials, thereby mitigating the negative impact of construction industry on environment. This article highlights a summary of the study on the utilization of polyethylene terephthalate in flexible pavement by asphalt and Styrofoam utilization for sound proofing. Inclusion of plastic waste as a substitute of aggregate in the manufacturing of paver blocks, bricks, tiles, concrete and roads has been comprehensively reviewed. The researcher data exhibits that properties of asphalt can be improved by modification with PET plastic suitable for construction industry. Also, Styrofoam utilization can used in wall panel sound proof insulator, provide safety against hearing problem, enhances the military equipment's in terms of weight resulting in easily workable and safer material. Later, LDPE is used for creating better environment by replacing cement for production of paver blocks.

Keywords: Polyethylene Terephthalate, Styrofoam, LDPE, Asphalt, Sound Proof, Paver Blocks

1. INTRODUCTION

In this modern eon design for the circular economy has evolved as a primary strategy for researchers in the field of sustainable design (Sauerwein et al. 2019). Extension of material life and complete recovery of materials and its structure are the basic components of this methodology, where a progressive system between recovery procedures ensures the stability of the material, i.e., the degree to which the material remains the same from its originality(den Hollander, Bakker, and Hultink 2017). In other words, in the material circular economy, the value of the product is maintained as long as possible and the waste is minimized (Nugent and Rhinard 2015). The circular economy is recommended as a strategy to tackle rapid economic change that is compatible with sustainable economic development and environmental protection(Foundation 2012; MacArthur 2013; Nugent and Rhinard 2015).India ranks among the top 10 countries in the world in waste generation. It is estimated that the country generates 30 million tons of waste per year with about 25% entering the composting, incinerating, and landfill waste streams. The production of waste around the world is on the increase and in general is pernicious towards the environment causing pollution that harms aquatic species and humans. Plastic production has increased worldwide from 1.5 million metric tons in 1950 to 359 million metric tons in 2018 (Garside 2019). The production of plastics worldwide from 1950 to 2018 is shown in Figure.

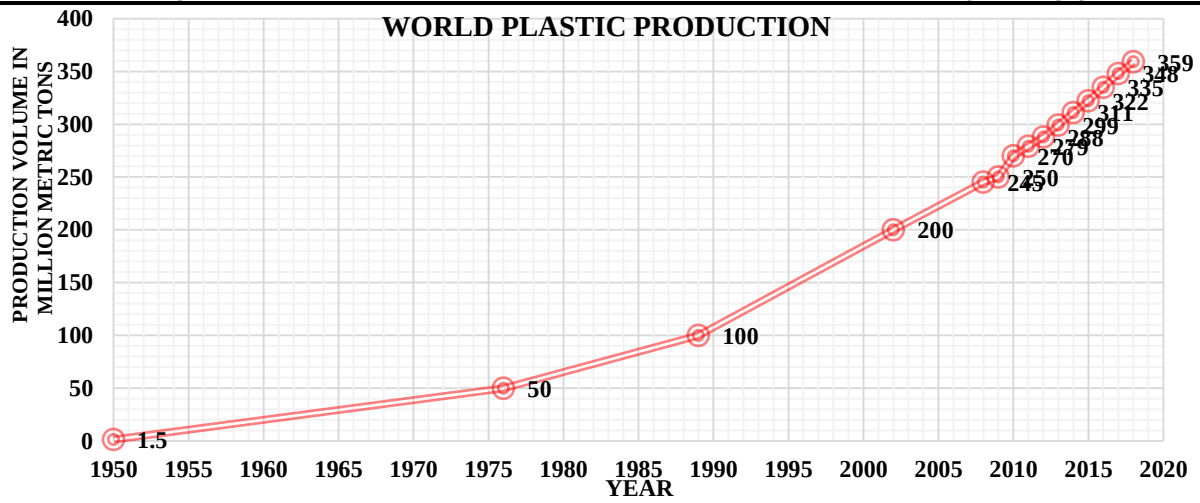

Fig. 1 Global Plastics Production from 1950 to 2018 (Geyer, Jambeck, and Law 2017)

Due to their mass production and relatively low cost, plastic is increasingly used in day-to-day products for humans. Between 1950 and 2015, 8300 million metric tons of plastics have been produced, in which only 500 million metric tons were recycled (Geyer, Jambeck, and Law 2017).Figure shows the number of plastics produced, recycled, and disposed between 1950 and 2015, as summarized by (Geyer, Jambeck, and Law 2017).The plastic used in different products are of various mechanical properties, shapes, sizes, and colors that cause hindrances in their effective disposal. It is therefore necessary to treat and separate polymers according to their physical and chemical properties, which could lead to effective waste management. Incineration, recycling, landfilling, and carbonization are some of the plastic disposal methods in practice (Chen et al. 2020). Between 2000 and 2025 the waste composition of Indian garbage will undergo the following changes:

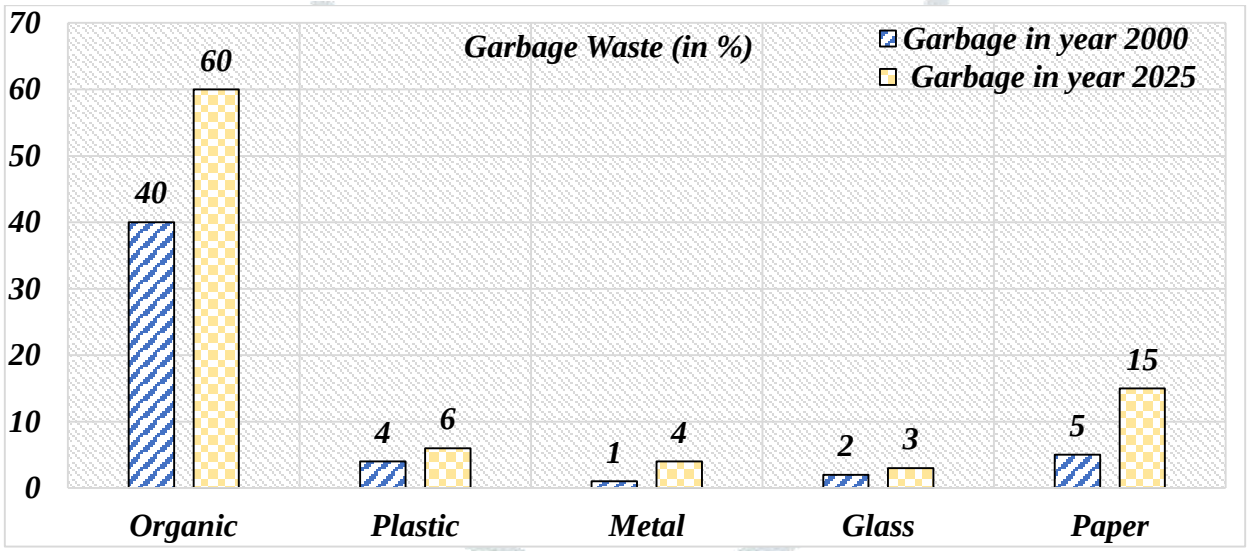

Fig. 2 Garbage Production in India

Recycling of waste generated from industrial and agricultural activities as building materials appears to be viable solution not only to such pollution problem but also to the problem of economic design of buildings. Paver Blocks belongs to the wide family of construction materials since it is mainly used for the construction of outer and inner walls in buildings. The concrete blocks industry is the most indicated technological activity sector to absorb solid waste due to the large quantity of raw material used by the sector as well as by the large volume of final products in construction (Andreola et al. 2005)

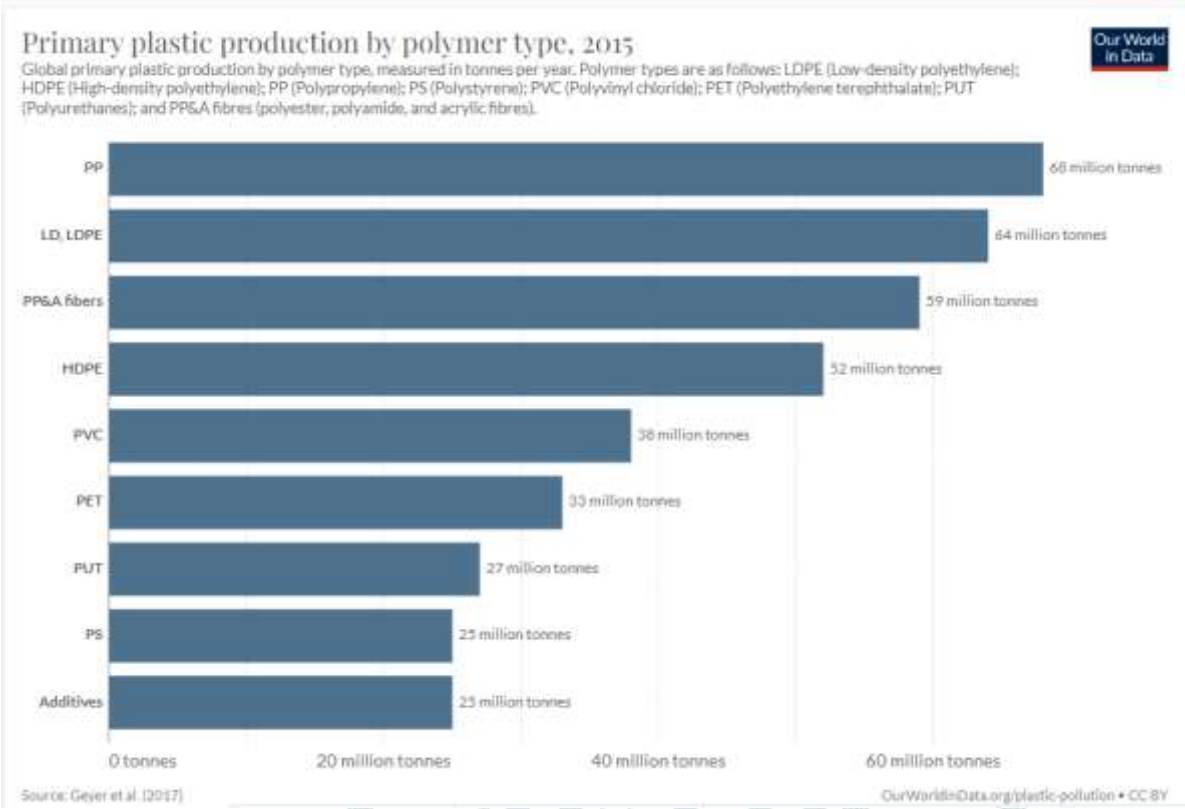

Fig. 3 Plastic Production in World by Different Plastic Category

1.1 Origin of Plastic

The man-made plastic was originally discovered in 1862 by Alexander Parkes at the International exhibition in London. Later, this plastic was also known as "Parkesine" in the markets as white or ivory alternate. In 1907, after 45 years later Parkesine was discovered from organic the Bakelite come into existence founded by Dr. Leo Bakeland also known as first synthetic plastic. This was the start of modern plastics. In 1920, polymers were discovered by Herman Staudinger. Later in 1933 to 1945 after the World War-II in England, Polyethylene was created and was held secret for use of light weight insulate radar cabling. It was placed in airplanes giving significant advantage to England over Germans. In 1933, Polystyrene was also created but quickly replaced by co-polymer in rubber. In 1939, Nylon was created by Dupont company situated in USA to manufacture synthetic silk which was quickly adopted by military for use in parachutes and ropes. In 1950, as a growing and developing countries using plastic in daily purpose material such as plastic milk, bottles made by High density polymers. In 1965 space center were also used polysulfide family thermoplastic for gold-film screens. In 1970 Oil companies drives consumer to focus on biodegradable plastics to conserve our environment due to mass use of plastic. Today plastics are popular for their strength and design flexibility, finding innovative applications ranging from hospital, medical stores, cosmetic stores to automotive, space, infrastructure and everything in between. Plastics are very well-known product but very less disposable plastic are commonly used to make sustainable environment.

1.2 Types of Plastics

There are around Seven types of plastic in existence, all are recyclable in its own way

1) Polyethylene Terephthalate (PET or PETE)
2) High-Density Polyethylene (HDPE)
3) Polyvinyl Chloride (PVC or Vinyl)
4) Low-Density Polyethylene (LDPE)
5) Polypropylene (PP)
6) Polystyrene (PS or Styrofoam)
7) Other

Fig. 4 Types of Plastics

The main question come in our mind that whether all the plastics are the same. According to quote by *Tod Hardin, "Plastic: It's Not All the Same"*. There are hundreds of types of plastics also known to be polymers but only few were currently used. In every day goods or material, a little amount of plastic content is present. In order to maintain the environment, it is essential to fully understand about the types, uses and properties of plastics.

Table 1 Properties of Plastics

Types of Plastic	Density (g/cm^3)	Melting Point	Boiling Point
Polyethylene Terephthalate	1.38 g/cm^3	260°C	350°C
High-Density Polyethylene	0.95-0.97 g/cm^3	115-135°C	111.9 °C
Polyvinyl Chloride	1.4 g/ml at 25 °C (lit.)	170-195 °C	100 °C
Low-Density Polyethylene	0.91-0.94 g/cm^3	105 to 115°C	80°C-115°C
Polypropylene	0.9 g/ml at 25 °C and 1.406 g/cm^{3}at 20°C	160°C - 210°C	189 °C
Polystyrene or Styrofoam	0.96-1.05 g/cm^3	240 °C	430 °C
Other Plastics (Nylon 66)	1.14 g/cm^3	268.8 °C	452.1 °C

Table 2 Chemical Composition of Plastics

Plastics	Notations	Chemical Formula	Uses	Purpose
Polyethylene Terephthalate	PETE or PET	$(C_{10}H_8O_4)_n$	Water bottles, soda bottles, medical jars, Jelly jars	Containers for storage, plastic carpet, textiles, luggage bag
High-Density Polyethylene	HDPE	$(C_2H_4)_n$	Grocery bags, soap bottles	Plastic Crates, Fencing
Polyvinyl Chloride	PVC	$(C_2H_3Cl)n$	Tile, frames for window	Vinyl Flooring
Low-Density Polyethylene	LDPE	$(C_2H_4)_n$	Flexible lids	Garbage Cans
Polypropylene	PP	$(C_3H_6)n$	Kitchen utensils, diapers	Cables for Battery
Polystyrene or Styrofoam	PS	$(C_8H_8)_n$	Tiffin boxes, Bricks , Paver blocks	Insulation
Other Plastics (Nylon	-	$(C_{12}H_{22}N_2O_2)_n$	Eyeglasses, Plastic	Plastic Lumber

66)			DVD or CD	

2. Utilization of Polyethylene Terephthalate in Highway Industry

PET well known as Polyethylene terephthalate is polyesters developed by acid and alcohol polymerization. They are workable, durable and has thermal stability. The common applications of PET are diffraction sheets, fiber textiles, electrical appliance. The fiber bottles made by PET is around 60% of its total production (Awaja and Pavel 2005),(Sinha, Patel, and Patel 2010). Asphalt in flexible pavement as a binder has certain problems such as cracking damage, fatigue and rutting at low temperature. It still can be controlled by improving the refinement process which is difficult to achieve. Therefore, the modification is the only way to improve the quality of asphalt and by addition of polymers (Yuonne and Yajaira 2001). Also, the asphalt quality can also be improved by polymer which in turn improve rheological properties (Habib et al. 2011),(Ahmad, Razali, and Razelan 2017).

The factor responsible for Flexible pavement defects is due to change in temperature led to rutting at very high temperature and development of cracks in low temperatures areas(Kalantar, Karim, and Mahrez 2012),(Vasudevan et al. 2010),(Ahmadinia et al. 2012),(Casey et al. 2008),(Garcia-Morales et al. 2006). The development of road is essential due to heavy traffic volume, heavy load vehicles(Jain 1989). There are many more waste plastic may be used as an additive in asphalt pavement are PP (polypropylene), LDPE (low-density polyethylene), rubber latex, PVC (poly vinyl chloride) resulting in improvement of properties like durability, softening point , flash and fire point, resistance to fatigue(Hınıslıoğlu and Ağar 2004; Dallas 1986; Tayfur, Ozen, and Aksoy 2007; King, Muncy, and Prudhomme 1986).

(Ahmadinia et al. 2012) examined utilization of waste PET in stone mastic asphalt mixture in which 0% to 10 % variation of PET is carried out for evaluation of mechanical properties. The effective variation found was 6% by weight of asphalt having PET. (Kalantar, Karim, and Mahrez 2012)investigate the utilization of PET into bitumen mixture in which bitumen was melted at 150 degrees Celsius with mix-proportion of 2% to 10% by weight. The report exhibit that there is significant resistance against rutting and resistance to deformation as compared to conventional mixture. The result also effective against gas evolution when heated at 120- 165° Celsius and decomposes at 270°C evolving no harmful gases(Menaria and Sankhla 2015).

The PET also utilized for the advancement of paver blocks to reduce environment pollutant and natural resources are used in maximization. The past researchers have made an attempt to minimize the consumption of cement by replacing it with fly-ash also to reduce global warming situations PET is partially replaced to form paver blocks. The report shows that use of PET has increased the strength of paver block after 30% replacement(Nivetha et al. 2016). The existence of waste in form of plastic in large quantities especially from industry waste such as Polypropylene (PP) and Polyethylene Terephthalate (PET) are utilized now a days as an alternative replacement of aggregate in concrete. The biggest problem is harm to environment by disposals of plastic because the plastics are least bio-degradable. The recycled PET studied by researchers and replaced in varying percentage from 10 % to 30 % by weight. The result shows that the self-weight of paver blocks is reduced up to 15% by weight. It is strongly recommended to use recycled plastic to reduce the pollutant in environment(Tapkire et al. 2014).

3. Utilization of Light Density Polyethylene (LDPE) in Construction Industry

The problem day by day is rising for contamination of water and air due to increase in production of plastic waste. The records says that LDPE production was 186.58 thousand metric tons in year 2013 was increased by 3.3 times in year 2020 i.e., 613.29 thousand metric tons(Statista 2021). The burning and disposal of plastic waste creating harm to the environment. Many researches have investigated on waste plastic such as bottles, bags, frozen food lids, flexible grocery bags for reducing its presence in the environment. The study is on LDPE plastic bags shredded into pieces then melted and added with sand. The paver blocks are made by varying percentage of waste to obtain best suitable mix. The result shows that paver blocks with plastic is absorbing less water, less weight and cost-effective when compared with conventional paver blocks(Nagesh and Abhishek 2019). The industrial product such as polypropylene and PET is studied for the partial replacement of the conventional aggregate. The possibility of plastic can be used for replacement is 20% as studied by the researchers(Tapkire et al. 2014).

4. Utilization of Waste Polystyrene in Medical Industry

The past research on the development of concrete is such that light weight concrete is mixed with weightless polystyrene by partially replacing with aggregate(Suprapto siswosukarto, Ashar Saputra 2017). Noise can be termed as unpleasant and unwanted sound which can cause disturbance(Daniel 2007). In developing countries, over eighty percent people suffer from noise hearing loss(Chadambuka, Mususa, and Muteti 2013).The best engineering equipment to control or reduce the sound level to avoid disturbance is sound proofing material or sound absorbing materials. Previous researchers have studied and used materials such as sawdust, rice husk, glass wool, leaf waste, cotton as a sound absorbing material(Korniejenko et al. 2016; Chen, Li, and Ren 2010; Zulkifli et al. 2009; Kang et al. 2012; Qin et al. 2011; Fachrul, Yulyanto, and Merya 2011; Zou, Huda, and Yang 2010; Rozli and Zulkarnain 2010).Though, this fiber has safety features as effective to lungs and eyes diseases especially glass wool. But there are disadvantages also as they are poor resistance to fire and quickly absorb water(Ali et al. 2018).

The polystyrene utilization in bricks prevent the increasing prevalence of loss of hearing. (Nasri and Shofwati 2018)studied about the Styrofoam material through which sound can be reduced. The fine aggregate and cement mixture with 1:4 and 1:6 composition was made in addition to Styrofoam waste with varying percentage from 0% to 80 % to determine acoustical property using microphones tube. The Styrofoam is also added in construction industry such as in brick, paver blocks productions since it creates

an air cavity in between cement-sand(Sudipta and Sudarsana 2009).The researches also studied that by utilizing Styrofoam with thickness ranging from 0.3cm to 0.4 cm the sound absorbing coefficient is 0.62 Hz frequency(Novak, Ule, and Cert 2011).

5. Conclusions

The following are the major aspects that can be drawn from the data accumulated from some research works of literature: According to scientific reports, experimental works, and researches, plastic waste such as recycled PET is suitable for use in the bituminous mixture in highway construction. The use of PET would improve the properties of flexible pavement by increasing its stability, stiffness, and viscosity; as a result, it could improve stripping, thermal cracking, temperature susceptibility, fatigue damage, and rutting resistance. Last but not least, using polymers as a modifier to the bituminous mixture would solve the problem of environmentally friendly waste plastic disposal. Further, the Styrofoam is play key role in health industry by reducing the ear problems in turns providing safety by modification. The LDPE are majorly reducing the environmental problems by replacing cement for production of paver blocks still more investigation is required to achieve optimum configurations and range of their utilization limit. The report also concludes that in case of production in paver blocks increase in percentage of plastic up to 20 % does not affect the properties of concrete. The challenge is to reduce the waste coming out from the industries, factories for the sustainable environment.

References

1. Ahmad, A. F., A. R. Razali, and I. S.M. Razelan. 2017. "Utilization of Polyethylene Terephthalate (PET) in Asphalt Pavement: A Review." *IOP Conference Series: Materials Science and Engineering* 203 (1). https://doi.org/10.1088/1757-899X/203/1/012004.
2. Ahmadinia, Esmaeil, Majid Zargar, Mohamed Rehan Karim, Mahrez Abdelaziz, and Ebrahim Ahmadinia. 2012. "Performance Evaluation of Utilization of Waste Polyethylene Terephthalate (PET) in Stone Mastic Asphalt." *Construction and Building Materials* 36: 984–89.
3. Ali, Azam, Khubab Shaker, Yasir Nawab, Madeha Jabbar, Tanveer Hussain, Jiri Militky, and Vijay Baheti. 2018. "Hydrophobic Treatment of Natural Fibers and Their Composites—A Review." *Journal of Industrial Textiles* 47 (8): 2153–83.
4. Andreola, Nora Maria, Luisa Barbieri, Isabella Lancellotti, and Paolo Pozzi. 2005. "Recycling Industrial Waste in Brick Manufacture. Part 1."
5. Awaja, Firas, and Dumitru Pavel. 2005. "Recycling of PET." *European Polymer Journal* 41 (7): 1453–77.
6. Casey, Donnchadh, Ciaran McNally, Amanda Gibney, and Michael D Gilchrist. 2008. "Development of a Recycled Polymer Modified Binder for Use in Stone Mastic Asphalt." *Resources, Conservation and Recycling* 52 (10): 1167–74.
7. Chadambuka, A, F Mususa, and S Muteti. 2013. "Prevalence of Noise Induced Hearing Loss among Employees at a Mining Industry in Zimbabwe." *African Health Sciences* 13 (4): 899–906.
8. Chen, Dakai, Jing Li, and Jie Ren. 2010. "Study on Sound Absorption Property of Ramie Fiber Reinforced Poly (l-Lactic Acid) Composites: Morphology and Properties." *Composites Part A: Applied Science and Manufacturing* 41 (8): 1012–18.
9. Dallas, N. 1986. "Little: AN Additive of Asphalt Additives to Reduce Permanent Deformation and Cracking in Asphalt Pavements: A Brief Synopsis of On Going Research"." *Proceedings of the Association of Asphalt Paving Technologists (AAPT)* 55: 314–20.
10. Daniel, Eileen. 2007. "Noise and Hearing Loss: A Review." *Journal of School Health* 77 (5): 225–31.
11. Fachrul, Melati Ferianita, Wisnu Eka Yulyanto, and Asharani Merya. 2011. "Desain Penyusunan Peredam Kebisingan Menggunakan Plywood, Busa, Tray Dan Sabut Pada Sumber Statis." *Makara Journal of Technology* 15 (1): 150888.
12. Foundation, Ellen MacArthur. 2012. *Towards the Circular Economy*. Ellen MacArthur Foundation.
13. Garcia-Morales, M, P Partal, F J Navarro, and C Gallegos. 2006. "Effect of Waste Polymer Addition on the Rheology of Modified Bitumen." *Fuel* 85 (7–8): 936–43.
14. Geyer, Roland, Jenna R Jambeck, and Kara Lavender Law. 2017. "Production, Use, and Fate of All Plastics Ever Made." *Science Advances* 3 (7): e1700782.
15. Habib, Noor Zainab, I Kamaruddin, Madzalan Napiah, and M Tan Isa. 2011. "Rheological Properties of Polyethylene and Polypropylene Modified Bitumen." *International Journal Civil and Environmental Engineering* 3 (2): 96–100.
16. Hınıslıoğlu, Sinan, and Emine Ağar. 2004. "Use of Waste High Density Polyethylene as Bitumen Modifier in Asphalt Concrete Mix." *Materials Letters* 58 (3–4): 267–71.
17. Hollander, Marcel C. den, Conny A. Bakker, and Erik Jan Hultink. 2017. "Product Design in a Circular Economy: Development of a Typology of Key Concepts and Terms." *Journal of Industrial Ecology* 21 (3): 517–25. https://doi.org/10.1111/jiec.12610.
18. Jain, S. Bose and P.K. 1989. "Laboratory Studies on the Use of Organic Polymers in Improvement of Bituminous Road Surfacings." *Highway Research Bulletin,(New Delhi)* 38.
19. Kalantar, Zahra Niloofar, Mohamed Rehan Karim, and Abdelaziz Mahrez. 2012. "A Review of Using Waste and Virgin Polymer in Pavement." *Construction and Building Materials* 33: 55–62.
20. Kang, Chun-Won, Seung-Won Oh, Tae-Bong Lee, Wook Kang, and Junji Matsumura. 2012. "Sound Absorption Capability and Mechanical Properties of a Composite Rice Hull and Sawdust Board." *Journal of Wood Science* 58 (3): 273–78.
21. King, G N, H W Muncy, and J B Prudhomme. 1986. "POLYMER MODIFICATION: BINDER'S EFFECT ON MIX PROPERTIES (WITH DISCUSSION)." In *Association of Asphalt Paving Technologists Proc*. Vol. 55.
22. Korniejenko, K, E Frączek, E Pytlak, and M Adamski. 2016. "Mechanical Properties of Geopolymer Composites Reinforced with Natural Fibers." *Procedia Engineering* 151: 388–93.
23. MacArthur, Ellen. 2013. "Towards the Circular Economy: Opportunities for the Consumer Goods Sector." *Ellen MacArthur Foundation*.
24. Menaria, Yash, and Rupal Sankhla. 2015. "Use of Waste Plastic in Flexible Pavements-Green Roads." *Open Journal of Civil Engineering* 5 (03): 299.
25. Nagesh, M A, and A E Abhishek. 2019. "Waste Plastic Use in Paver Blocks." *SAMRIDDHI: A Journal of Physical Sciences,*

Engineering and Technology 11 (SUP).
26. Nasri, Sjahrul Meizar, and Iting Shofwati. 2018. "Utilization of Styrofoam as Soundproofing Material with Auditory Frequency Range." *Kesmas* 13 (2): 99–104. https://doi.org/10.21109/kesmas.v13i2.2633.
27. Nivetha, C, M Rubiya, S Shobana, Vaijayanthi R G Viswanathan M E, and R M E Vasanthi. 2016. "PRODUCTION OF PLASTIC PAVER BLOCK FROM THE SOLID WASTE (QUARRY DUST , FLYASH & PET)" 11 (2): 1078–79.
28. Novak, Colin, Helen Ule, and Jason Kunio INCE Bd Cert. 2011. "Comparative Study of the ASTM E1050 Standard for Different Impedance Tube Lengths." In *INTER-NOISE and NOISE-CON Congress and Conference Proceedings*, 1:815–22. Institute of Noise Control Engineering.
29. Nugent, Neill, and Mark Rhinard. 2015. *The European Commission*. Macmillan International Higher Education.
30. Qin, Lijun, Jianhui Qiu, Mingzhu Liu, Shenglong Ding, Liang Shao, Shaoyu Lü, Guohong Zhang, Yang Zhao, and Xie Fu. 2011. "Mechanical and Thermal Properties of Poly (Lactic Acid) Composites with Rice Straw Fiber Modified by Poly (Butyl Acrylate)." *Chemical Engineering Journal* 166 (2): 772–78.
31. Rozli, Zulkifli, and Zulkarnain Zulkarnain. 2010. "Noise Control Using Coconut Coir Fiber Sound Absorber with Porous Layer Backing and Perforated Panel." *American Journal of Applied Sciences* 7 (2): 260–64.
32. Sauerwein, Marita, Eugeni Doubrovski, Ruud Balkenende, and Conny Bakker. 2019. "Exploring the Potential of Additive Manufacturing for Product Design in a Circular Economy." *Journal of Cleaner Production* 226: 1138–49. https://doi.org/10.1016/j.jclepro.2019.04.108.
33. Sinha, Vijaykumar, Mayank R Patel, and Jigar V Patel. 2010. "PET Waste Management by Chemical Recycling: A Review." *Journal of Polymers and the Environment* 18 (1): 8–25.
34. Statista. 2021. "Production Volume of Low-Density Polyethylene in India." 2021. https://www.statista.com/statistics/1262751/india-low-density-polyethylene-production-volume/.
35. Sudipta, I Gusti Ketut, and Ketut Sudarsana. 2009. "Permeabilitas Beton Dengan Penambahan Styrofoam." *Jurnal Ilmiah Teknik Sipil* 13 (2).
36. Suprapto siswosukarto, Ashar Saputra, I Gede Yohan Kafrain. 2017. "Utilization of Polystyrene Waste for Wall Panel to Produce Green Construction Materials" 171: 664–71. https://doi.org/10.1016/j.proeng.2017.01.406.
37. Tapkire, Ganesh, Satish Parihar, Pramod Patil, and Hemraj R Kumavat. 2014. "Recycled Plastic Used in Concrete Paver Block." *International Journal of Research in Engineering and Technology* 03 (21): 33–35. https://doi.org/10.15623/ijret.2014.0321009.
38. Tayfur, Süreyya, Halit Ozen, and Atakan Aksoy. 2007. "Investigation of Rutting Performance of Asphalt Mixtures Containing Polymer Modifiers." *Construction and Building Materials* 21 (2): 328–37.
39. Vasudevan, RNSK, R Velkennedy, A Ramalinga Chandra Sekar, and B Sundarakannan. 2010. "Utilization of Waste Polymers for Flexible Pavement and Easy Disposal of Waste Polymers." *International Journal of Pavement Research and Technology* 3 (1): 34–42.
40. Yuonne, B, and MPMR Yajaira. 2001. "Polymer Modified Asphalt." *Vision Technological* 9 (1): 39–48.
41. Zou, Yi, Shah Huda, and Yiqi Yang. 2010. "Lightweight Composites from Long Wheat Straw and Polypropylene Web." *Bioresource Technology* 101 (6): 2026–33.
42. Zulkifli, R, M J Mohd Nor, A R Ismail, M Z Nuawi, and M F Mat Tahir. 2009. "Effect of Perforated Size and Air Gap Thickness on Acoustic Properties of Coir Fibre Sound Absorption Panels." *European Journal of Scientific Research* 28 (2): 242–52.