International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 5s, 2025
https://www.theaspd.com/ijes.php

Evaluation Of Strength Characteristics Of Flexible Pavement Layers Modified With Plastic Waste

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Abstract. *Plastics became a part of every day lives due to low cost, durability, and functionality. The non-biodegradable nature of plastics is a menace to the environment and decades of efforts to effectively recycle plastics have been unrewarding since repeated recycling deteriorates the quality of plastic and the cost of collection, sorting, cleaning and recycling exceeds the cost of virgin plastic in developed countries whereas the developing countries lack infrastructure and awareness needed for effective recycling of plastic waste (PW). Significant research has established that un-treated PW is entering the food chain of marine species and can potentially enter the human food chain as well. Disposal of PW in land fill has a threat of leeching of harmful chemicals into the environment and adverse effect on ground water recharge whereas incineration releases significant amount of greenhouse gases making PW disposal an unfeasible solution. The situation demands a circular economic approach to upcycling PW. Since the year 2001 PW is used in India for road construction, this has helped in creating circular economy to upcycle plastic waste and making roads sustainable. India alone aims to construct 34,800 km of national highways by 2026, projects of this magnitude will consume enormous amount of soil, aggregate and bitumen. This paper examines the performance of PW modified soil and bitumen to assess the suitability of PW modified roads as an effective, economical and sustainable alternative for flexible pavement construction.*

INTRODUCTION

The last decade has witnessed an increase in plastic productionof about 11.4 million metric tons every yearglobally[1].The plastic industry is expanding at a compound annual growth rate (CAGR) of 10% and per capita consumption of plastics would be 20 kg annually[2]. About 80 million metric tons of plastic waste is mis managed which reaches landfills and oceans, at this pace the amount of mis managed plastic waste may reach 152 million metric tons by 2060[3]. This volume of plastic production and consumption would considerably increase generation of plastic waste and related Greenhouse gas (GHG) emissions by 2050[4]. India produces 15,342 tonnes of plastic waste per day and absence of an organized mechanism to handle this waste is affecting India's sustainable development goal(SDG) rating[5].Heterogeneous and littered nature of plastic waste makes recycling uneconomical making landfilling the ultimate solution for developing countries[6]. PW escapes landfills through tidal and wind forces resulting in choking of drains and releases GHG, to address this issue Extended Producers Responsibility (EPR) is introduced in the plastic waste management rules 2018[7]. However global studies have suggested that management of plastic waste is the biggest challenge for all countries, It has been anticipated that about 90% of the waste plastics are not recycled this situation will be further raised by China's import ban on waste plastics[8].About 95% of all plastic solid waste (PSW) is packaging material like milk pouches, carry bags and food wrappers. It is predicted that by 2050 the PSW in oceans will outweigh fish[9]. Globally only about 9% of the produced plastic gets recycled, 12% isburned, and 79% isamassedeither in landfills or the natural environment[10]. Plastics exposed to sunlight and wave action reduces into microplastic particles less than 5 mm in size[11].Oceanic birds and all forms of marine species are displaying ill effects due to ingestion of plastic particles[12]. Studies have revealed that microplastics can translocate to all human organs[13]. A study conducted in China predicted annual microplastic intake from salt to be 37 particles per individual[14].Consumption of micro and nano plastic increases inflammatory response, chemical transfer of adsorbed chemical pollutants and disorder of the gut microbiome[15]. 80% plastic waste in the oceans is believed to come from land-based sources[16].Waste leakage is inseparably coupled with economic growth, local infrastructure, and legislation[17], These aspects have awakened public concerns requiring legislation for minimizing the wastes getting into the environment[18]. Cost of handling PSWforces several developing countries and communities to abandon it in open landfill sites[19]. It is likely that India will become the leading Mismanaged Plastic Waste (MPW) generating country by 2035[20]. Available literature and ground reports validate that plastic recycling is not efficient in developed and developing countries alike. The issue of plastic litter is transforming into a health hazard owing to its access in the food chain, and hence upcycling of plastic waste into road construction can be a real solution due to the strength and durability of plastics.Further this can create a circular economy of plastic waste management and encourage efficient handling of plastic waste. Studies have reported improvement in rutting properties of flexible pavements due to addition of PSW[21]

SUSTAINABILITY IN ROAD CONSTRUCTION

Road constructionactivities across the globeproduces the highest level of greenhouse gasthrough fossil fuels used in mining, transportation and paving works[22]. Globally road construction activities are responsible for 22% energy consumption, 25% of fossil fuel consumption and 30% of air pollutants and greenhouse gas emissions[23]. The concept of sustainable development is aimed at utilization of materials for present needs while ensuring that future generations are not deprived of such materials, In January 2022 the state of Tamil Nadu faced severe shortage of soil and construction aggregate for road construction. The situation forced National Highways Authority of India (NHAI) to exclude four major highway projects[24]. It is therefore important to find alternative materials to enhance the strength of conventional road construction materials which can reduce layer thickness and save natural material and increase the durability of pavements to ensure long lifespan requiring minimum material for repair and maintenance of roads. Plastic being a strong and durable material having its presence in abundance in the landfills across the country can be explored to be a suitable strength enhancement material to make roads sustainable.

REINFORCED SOIL AS SUBGRADE

Poor load bearing capacity of subgrade causes longitudinal cracking and pavement failures. Whenever weak soils are encountered, they arestabilized using lime, cement, fly ash etc. These materials are expensive, and they have anadverse impact on the environment and hence various types of fibers, geo textiles and geo grids are often used to improve strength of weak soils. This section of the paper focuses on the use of natural and artificial fibers as reinforcing agent to improve bearing capacity of soil. Experiments have confirmedincrease in properties and behavior of sands in combination with plastic[25,26].Soft soils blended with coir fiber in concentration of 0-1% improvsdensity, elastic modulus as well as CBR results[27].Polypropylene (PP) fiber with different aspect ratiowhen added to soil exhibiteda rise of 4.33%, 6.42%, 18.03% in CBR value and enhanced the unconfined compressive strength (UCS) to 7.16, 9.05, and 9.71 megapascal (MPa) correspondingly[28].Natural fibers and polyethylene terephthalate (PET) when blended with soil reveal that deviatoric stress at 1% of natural fibers was 65 kilopascal (kPa) and that for plastic fiber was 80 kPa. By further increasing concentration of fibers to 3% it was found that deviatoric stress was 225 and 245 kPa for natural and plastic fiber. This study demonstratessuperior performance of plastic fiber as compared to natural fiber[29].Expansive soil when added PP fiber displays improved swell capacity at 0.5 and 1% PP fiber concentration[30].Sandsreinforced with plastic multioriented hexa-pods enhanced the deviatoric stress and angle of internal friction as equated to un-reinforced sands[31].Fiber-reinforced soil added with 0%, 0.5%, and 1% indicate reduction in volume changesdue to thefreeze-thaw cycles[32]. Glass fiber (GF) reinforced cohesive soil exhibited substantial improvement in soaked CBR value and secant modulus [33].Shear strength and CBR value of PW reinforced sands revealimprovement in shear strength and penetration resistance at 0.75% concentration, further it displayed an increase of 9% in penetration resistance [34].Sisal fibers when added to clayey soil demonstrate crack reduction of 74% and surface crack reduction of 35% at 1% fiber content[35].PW added to clayey soil in 1.5 % to 3.0 % concentration enhances shear strength and reduces compressibility of plain clay[36].Sand mixed with construction & demolition (C&D) waste and crushed bricks (CB) with 3% and 5% of PET demonstrates 80% CBR value[37]. Table 1 summarizes various studies conducted on weak soils reinforced with natural and artificial fibers and the test parameters. It is observed that beyond 3% concentration the soil characteristics are deteriorating. Most papers demonstrate that artificial fiber imparts more strength as compared to natural fibers. Manufacturing PP fibers causes pollution; it may be sustainable approach to process PW into reinforcing fibers or grids to strengthen soil properties. Few studies are reported on utilization of PW as a soil reinforcing agent.

TABLE 1

Soil	Fiber	Test parameter	Optimum concentration	Reference
Clay	Coir	CBR	1%	27
Sand	PP	CBR	3%	28
Silty clay	PET	Triaxial strength	3%	29
Black cotton	PP	Free swell index	1%	30
Coarse sand	PET	Triaxial strength	2%	31
Clay	PP	Triaxial strength	1%	32
Clay	GF	CBR	1%	33
Sand	PET	Triaxial strength	0.75%	34
Clay	Sisal	Crack width	1%	35
Clay	PW	Triaxial strength	1.5%	36
Sand	PET	CBR	5%	37

PLASTIC MODIFIED BITUMEN LAYERS

To increase utilization of PW in secondary purposes they have been studied as bitumen modifier and the results show improvement in viscosity and stiffness of bitumen at service temperatures[38]. PW as a binder modifier convey the benefit of a cheap and effective method of improving conventional bitumen binder's performance and is also an alternative way to utilize PW[39,40].PW modified bituminous binders depict a predominantly viscous performance and are resistant to heat, radiation with superior creep and recovery performances[41,21].Rheological and thermal behavior of bitumen modified with varying composition of PW exhibited better performance as compared to un-modified bitumen[42].PW composite binder reduces rutting, improves creep modulus and creep recovery in bituminous concrete[43].PW enhances elastic recovery of base bitumen this results in reduced thermal sensitivity and reduced aging rate of the modified bitumen[44].Partial substitution of bitumen with PW results up to 16% increment in strength which makes pavement environment friendly at less material cost[45].PET blended bitumen shows significant enhancement in mechanical and rheological properties of the bituminous mixtures[46,47,48,49]. PET enhanced the resilience and the long-term sustainability of the pavement[50].PW shredded fibers in 4% concentration blendedwith the base binder improves its penetration value, softening point and viscosity[51].Bitumen mixture added with recycled plastics improves modulus of resilience (M_R)of pavements[52].Chemically recycled PET showed improvement in rutting, fatigue and creep performance of bitumenalong with efficient increase the resistance to moistureinduced damage of asphalt mixture[53,54].PET fibers mixed into hot mixed asphalt (HMA) produced remarkable increase in the indirect and bending beam fatigue tests[55]. PET modified bitumendisplayed increased softening point and reduced penetration value[56,57].PET improved theresistance of mix against permanent deformation and improved the stiffness of the mix forStone mastic asphalt (SMA)[58,59].Styrene butadiene styrene (SBS) is a widely used bitumen modifier, LDPE replaced with 1% SBS exhibited similar strength. Ethylene vinyl acetate (EVA) another bitumen modifier added with LPDE gives similar strength and higher softening point than SBS modified bitumen at an economical cost[60].Bitumen mixed with LDPEdisplayed reduced penetration value and increased softening point[61].Milk packaging added to dense bituminous macadam (DBM)deliver better results compared with conventional bitumen[62].Dynamic moduli and rutting behavior of bitumen at high temperatures were enhanced due to WPMP[63].SMA added with high density polyethylene (HDPE) out-performs traditional binders in rut resistance[64,65].LDPE enhanced aggregate's wear resistance whereas HDPE enhances aggregate's impact value, among the two HDPE-modified HMA exhibited the highest rutting resistance[66]. Multiple stress creep recovery(MSCR) tests suggest stress sensitivity of HDPE-modified binder is considerable as compared to base binder[67]. Table 2 summarizes various studies performed on bituminous mixes blended with various types of plastic, test parameter and type of pavement layer for which the modified mixed is designed.

TABLE 2

Mix type	Type of plastic	Test parameter	Optimum concentration	Reference
Surface course	Generic	Marshall stability	2%	39,40
Surface course	Generic	Viscosity, Softening point	4%	41,42
Surface course	PET	Marshall stability, Viscosity	2-5%	46,47,48
Surface course	PET	Ageing, Softening point	3%	50
Surface course	PET	Penetration value, Viscosity	2%	68
Generic	PET	M_R	4%	52
Surface course	PET	Rutting, Fatigue, Creep	3-4%	53,54
HMA	PET	Fatigue	2%	55
Surface course	PET	Penetration value, Softening point	3-5%	56
Surface course	PET	Deformation, Stiffness	5%	58
SMA	PET	Rutting	3%	59
Surface course	LDPE	Marshall stability, Viscosity	3%	60
Surface course	LDPE	Penetration value, Softening point	5%	61
DBM	WPMP	Marshall stability	2%	62
DBM	WPMP	$M_{R,}$ Rutting	4%	63
HMA	LDPE & HDPE	Rutting	4%	66
SMA	HDPE	Penetration value, Softening point	3%	64,65

CHALLENGES IN UTILIZATION OF PW FOR ROAD CONSTRUCTION

Even though PW can enhance the strength of road subgrade as a reinforcement material, its large-scale utilization has significant challenges in collection, cleaning, sorting and finally processing into desired aspect ratio required forthe type of soil, its density and moisture characteristics.

PW modified bitumen exhibits better performance in rheological, strength and durability criteria making PW modified roads a sustainable alternative to traditional roads, however recent studies have highlighted ill effects of microplastics originating from the surface course of the road pavement. Here the health hazard caused by airborne microplastics outweighs the benefits imparted by PW in bitumen modification.

CONCLUSION

The latest research on utilization of PW in road construction shows encouraging results, most common type of PW used for enhancing strength of weak soils in subgrade was PET, it's use as a soil reinforcing agent is convenient since it is easy to clean as compared to other types of PW. PP also provides significant strength to weak soils, but they are not a waste material hence do not contribute to sustainability aspect of road construction. LDPE used for food packaging may be a suitable alternative to PP, but it's use has challenges mainly due to the presence of various oils and residue of food left in the packets. And therefore, a methodology to process the PW before it's usedfor soil reinforcement needs to be developed for wide scale application in road projects.

Apart from the type of PW,its aspect ratio and its concentration by weight of soil are most significant parameters affecting strength of PW reinforced subgrades.

As compared to other bitumen modifiers PET is most widely tested. LDPE, WPMP and HDPE give better strength as compared to PET, but they need to be cleaned thoroughly before being used as a bitumen modifier. 3-5% is the optimum replacement range for all types of PW. However, it is observed that PET and HDPE increase stiffness of modified bitumen, this may reduce flexibility of the modified mix and make pavement susceptible to brittle failure. A balance of optimum concentration for desired stiffness needs to be identified through rigorous testing for various concentrations and types of PW.

Utilization ofcross-linking agents may help to increase concentration of PW in modified bitumen at the same time provide flexibility to the modified mix.

Available literature shows potential for the use of various types of PW to construct stronger and failure resistant roads, enhanced strength may help in reducing layer thickness and increased life span of the roads requiring less repair and maintenance, both the benefits ultimately help in saving precious natural resourcesand making road construction sustainable. Wide scale use of PW may help in creation of a PW upcycling industry for marginal section of society.

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