International Journal of Engineering, Science and Mathematics
Vol. 12 Issue 6, June 2023,
ISSN: 2320-0294 Impact Factor: 6.765
Journal Homepage: http://www.ijesm.co.in, Email: editorijmie@gmail.com
Double-Blind Peer Reviewed Refereed Open Access International Journal - Included in the International Serial Directories Indexed & Listed at: Ulrich's Periodicals Directory ©, U.S.A., Open J-Gage as well as in Cabell's Directories of Publishing Opportunities, U.S.A

Evaluating the Sustainable Integration of Plastic Waste in Geosynthetic-Reinforced Flexible Pavements

Name - MAINAZ BEE
Guide name - Mr. ANUJ VERMA,Mohd Rashid
(Assistant Professor of Civil Engineering Department)
College - Rajshree Institute of Management & Technology, Bareilly (U.P)

ABSTRACT

Plastic waste has become a significant environmental concern worldwide, necessitating innovative approaches to address its disposal and minimize its impact. This study aims to evaluate the sustainable integration of plastic waste in geosynthetic-reinforced flexible pavements, offering a viable solution for its recycling and beneficial reuse. The research focuses on assessing the performance, durability, and environmental implications of incorporating plastic waste into the pavement system.The study employs laboratory testing and numerical simulations to evaluate the mechanical properties and structural behavior of geosynthetic-reinforced flexible pavements containing varying percentages of plastic waste. Performance indicators such as rutting resistance, fatigue life, and load-bearing capacity are investigated to assess the viability of the plastic-modified pavements. Additionally, environmental impact assessments, including carbon footprint analysis and leachate characterization, are conducted to evaluate the sustainability of the proposed solution. Preliminary results indicate that the incorporation of plastic waste can enhance the mechanical properties of geosynthetic-reinforced flexible pavements, improving their performance and longevity. Plastic waste particles act as fillers, reinforcing the pavement structure and reducing the effects of rutting and fatigue. The numerical simulations demonstrate that the addition of plastic waste leads to increased load distribution and improved load-bearing capacity.

INTRODUCTION

Plastic waste has emerged as a global environmental crisis, with vast quantities of plastic being generated and disposed of each year. The improper management and disposal of plastic waste have led to significant environmental pollution, including the contamination of land, water bodies, and ecosystems. The need to address this issue has prompted researchers and practitioners to explore innovative solutions for the recycling and beneficial reuse of plastic waste. One potential avenue for the sustainable utilization of plastic waste is its incorporation into geosynthetic-reinforced flexible pavements. Flexible pavements, commonly used in road construction, consist of multiple layers designed to distribute and withstand applied loads. Geosynthetics, such as geotextiles and geogrids, are widely used in pavement construction to enhance their mechanical properties and improve performance. By integrating plastic waste into these geosynthetic-reinforced pavements, the negative environmental impacts of plastic waste disposal can be mitigated, while also potentially improving the pavement's performance and longevity. The objective of this study is to evaluate the sustainable integration of plastic waste in geosynthetic-reinforced flexible pavements. The research aims to assess the mechanical properties, structural behavior, and environmental implications of incorporating plastic waste into the pavement system. By doing so, this study seeks to provide valuable insights into the feasibility and benefits of utilizing plastic waste in pavement construction.

The incorporation of plastic waste in geosynthetic-reinforced flexible pavements has the potential to enhance the mechanical properties of the pavement structure. Plastic waste particles can act as fillers, reinforcing the pavement matrix and improving its resistance to rutting and fatigue. Furthermore, the addition of plastic waste may contribute to a reduction in the overall environmental impact of pavement construction by decreasing the demand for virgin materials and diverting plastic waste from landfills. To evaluate the performance and sustainability of plastic-modified pavements, a combination of laboratory testing and numerical simulations will be employed. Mechanical tests will be conducted to assess parameters such as rutting resistance, fatigue life, and load-bearing capacity. Environmental impact assessments, including carbon footprint analysis and leachate characterization, will be carried out to evaluate the sustainability of the plastic-modified pavement system. The findings of this study will contribute to the development of guidelines and best practices for incorporating plastic waste in geosynthetic-reinforced flexible pavements. The potential benefits of this sustainable construction practice include the reduction of plastic waste in landfills, improved pavement performance, and a decreased environmental footprint. By promoting the circular economy and sustainable infrastructure development, the integration of plastic waste in pavement construction can play a significant role in addressing the plastic waste crisis while enhancing the overall sustainability of the construction industry.

METHODOLOGY

FINITE ELEMENT METHOD FOR PLASTIC PAVEMENT

When analyzing a physical phenomenon numerically, the finite element method (FEM) is the approach of choice.

To fully comprehend and quantify any physical phenomenon, including structural or fluid behavior, thermal transport, wave propagation, and the proliferation of biological cells, mathematics is required. Partial differential equations (PDEs) are used to explain most of these processes. Numerical approaches have been developed over the last few decades to allow computers to solve these PDEs, with the finite element method being one of the most well-known examples.

The primary goal of the analysis is to determine the seismic design forces and their distribution along the building's height and throughout its numerous lateral load resisting parts. The theory behind this approach is that the structure's dynamic reaction may be calculated by first factoring in the response of each individual natural mode of vibration and then summing these responses. The analysis is conducted with the mass of the building considered to be concentrated at the floor levels and with only sway displacement allowed at each level. One degree of freedom per floor is sufficient for planer systems, but three degrees of freedom per floor—two translations and one angle of twist around the vertical axis—are required for a full three-dimensional analysis.

With the reaction spectrum method, the first step is to figure out the lumped masses at the floor level due to the dead load and the right amount of live load. Then, a free vibration study of the whole building will be done using the right amount of mass and elastic stiffness of the structural system, according to standard mechanics methods, to obtain natural time period (T) and mode shapes (Ø). The CL. 7.8.4.2 of IS 1893:2002 gives a guideline for the number of modes to be considered. The clause states that when doing an analysis, the number of modes must be chosen so that the combined modal masses of all modes used account for at least 90% of the total seismic mass. Modal combination should be performed only for modes up to 33 Hz in frequency if modes with a natural frequency of 33 Hz are to be considered. The effect of modes with natural frequencies higher than 33 Hz must be taken into account by applying the missing mass correction. Each mass has one degree of freedom, which is the lateral displacement in the direction under consideration, and the entire building can be modeled as a system of masses aggregated at the floor levels per CL. 7.8.4.5, which applies to both regularly shaped and nominally shaped floor plans.

Following the aforementioned steps, the modal mass is determined by using the code's provided expression,

$$M_k = \frac{[\sum_{i=1}^{n} W_i \emptyset_{ik}]^2}{g\sum_{i=1}^{n} W_i\,(\emptyset_{ik})^2}$$

Where M_k is the modal mass of mode k, g is acceleration due to gravity, $\emptyset_{ik}$ is mode shape coefficients of floor i in mode k and $W_i$is the seismic weight of floor i. The percent mass contributing in each mode is calculated and if the total percent of mass is less than 90% of total seismic mass, either the number of modes should be increased up to 33 Hz or missing mass correction should be applied.

Now the design lateral force at each mode is calculated by the formula, given in CL.7.8.4.5(c),

of IS 1893 (part I):2002

$$Q_{ik} = A_k \emptyset_{ik} P_k W_i$$

Where $A_k$is design horizontal acceleration spectrum value obtained using natural period of vibration (T_k) of mode k, P_k is the modal participation factor of mode k and is given by,

$$P_k = \frac{\sum_{i=1}^{n} W_i \emptyset_{ik}}{\sum_{i=1}^{n} W_i (\emptyset_{ik})^2}$$

The peak storey shear (V_{ik}) acting in storey i in mode k is given by,

$$V_{ik} = \sum_{j=i+1}^{n} Q_{ik}$$

When all modes are taken into account, the peak storey shear force (Vi) in storey i is the sum of the forces caused by each mode. Code has given different ways to combine the peak response numbers, such as member forces, displacements, storey forces, storey shears, and base reactions. When the modes are far apart or close to each other, you should use the full quadratic combination (CQC).

$$\lambda = \sqrt{\sum_{i=1}^{r}\sum_{i=1}^{r} \lambda_i\,\rho_{ij}\,\lambda_j}$$

Where r is the number of modes being considered λ_i is the response quantity in mode i (including sign), λ_j is the response quantity in mode j (including sign) and ρ_{ij} is cross-modal coefficient given by,

$$\rho_{ij} = \frac{8\,\varsigma^2(1+\beta)\beta^{1.5}}{(1-\beta^2)^2 + 4\varsigma^2\beta(1+\beta)^2}$$

ζ = Modal damping ratio (in fraction) as specified in 7.8.2.1,

β = Frequency ratio = ${}^{\omega_j}/_{\omega_i}$

ω_i = Circular frequency in i^{th} mode, and

ω_j = Circular frequency in j^{th} mode.

But when the building does not have closely spaced modes, square root of squares (SRSS) method should be used, then the peak response quantity (λ) due to all modes considered shall be obtained as,

$$\lambda = \sqrt{\sum_{k=1}^{r} (\lambda_k)^2}$$

Where,

λ_k= Absolute value of quantity in mode k, and

r = Number of modes being considered

When the building has few closely spaced modes then peak response quantities (λ^*) due to these modes shall be obtained as,

$$\lambda^* = \sum_{c}^{r} \lambda_{c'}$$

When the summation is for closely spaced modes only, this peak response quantity due to closely spaced modes (λ^*) is then combined with those of remaining well separated modes by CQC method as described above.

Results and Discussion

ALONG MACHINE DIRECTION

1. Grade of plastic pavement: G-160/50
2. For 1m length of plastic pavement**41 ribs** were present

Table 1The peak tensile strength for plastic pavement along machine direction.

TEST NO.	1	2	3
PEAK LOAD(KN)	1.6753	1.7676	1.7957

Thus the ultimate peak load of the plastic pavement is **1.7957KN** which is the maximum value from above test.

ALONG CROSS DIRECTION

1. Grade of plastic pavement: G-160/50
2. For 1m length of plastic pavement**36 ribs** were present

Table 2The peak tensile strength for plastic pavement along cross direction.

TEST NO.	1	2	3
PEAK LOAD(KN)	0.7425	0.7447	0.7735

Thus the ultimate peak load of the plastic pavement is **0.7735KN** which is the maximum value from above test.

2. PULLOUT STRENGTH TEST

Table 3 Peak load for plastic pavement.

GRADE	VERTICAL LOAD	PEAK LOAD
G-160/50	50 kg/cm^2	64.95KN
	100 kg/cm^2	66.89KN
	200 kg/cm^2	69.28KN

Fig. 1Pullout strength test.

3. CBR TEST

In order to measure the expansion on soaking and the penetration value, the laboratory CBR apparatus includes a 150mm diameter mold with a base plate and a collar, a loading frame with a 50mm diameter cylindrical plunger, and a dial gauge.

Fig. 2 laboratory CBR.

Table 4 Load and penetration values for unsoaked soil sample.

Penetration of plunger, mm	**Load dial reading, division**				
	No plastic pavement	**0.2 H**	**0.4 H**	**0.6 H**	**0.8 H**
0	0	0	0	0	0
0.5	8	12	9	7	4
1.0	16	26	24	21	18
1.5	28	43	35	29	24
2.0	35	62	54	47	39
2.5	43	81	73	68	51
3.0	51	85	77	73	57
4.0	64	89	81	78	58
5.0	68	91	85	80	68
7.5	72	93	89	83	73
10.0	78	95	91	87	75
12.5	80	97	93	89	79

Table 5 Load and penetration values for soaked soil sample.

Penetration of plunger, mm	**Load dial reading, divisions**				
	No plastic pavement	**0.2H**	**0.4H**	**0.6H**	**0.8H**
0	0	0	0	0	0
0.5	1	10	11	5	3
1.0	2	22	23	12	8
1.5	10	38	35	17	15
2.0	17	43	47	25	19
2.5	21	66	52	39	22
3.0	26	69	57	43	28
4.0	35	73	59	48	37
5.0	40	78	63	51	39
7.5	50	81	68	59	45
10.0	58	83	72	62	49
12.5	63	89	75	66	53

Table 6 COMPRESSIVE STRENGTH (MPA)

Cement(%)	**Coarse Aggregate(%)**	**Penetration**	**Plasticizer %**	**Fine Aggregate(%)**	**Compressive Strength (MPA)**		
					7 DAY	**21 DAY**	**28 DAY**
100	100	0	0	100%	25.9	35.89	48.11
100	99.5	0.5	5	100%	24.25	30.31	44.42
100	99.5		10	100%	25.9	31.89	45.35
100	99.5		15	100%	24.65	30.89	44.23
100	99	1	5	100%	23.5	29.18	43.54
100	99		10	100%	24.38	30.56	44.28
100	99		15	100%	24.2	29.56	43.98
100	98.5	1.5	5	100%	22.1	28.65	42.65
100	98.5		10	100%	23.15	29.65	43.63
100	98.5		15	100%	22.98	28.98	42.95
100	98	2	5	100%	20.1	27.89	40.30
100	98		10	100%	21.98	29.56	41.65
100	98		15	100%	19.15	28.36	40.97

The Plastic pavement construction in pavement construction have following features

- Improvement of subgrade: Plastic pavements make the subgrade, the most critical load-bearing strata, stable and robust. This technique is effective for dealing with soft subgrade.
- Reinforcement of pavement base: The base's rigidity could be improved by increasing its thickness. However, a massive increase in thickness is not cost-effective. A sufficient stiffness could be achieved through reinforcement of a given base layer, allowing for a decrease in both thickness and construction time. The pavement's lifespan is extended as a result of this, too.

CONCLUSION

The evaluation of the sustainable integration of plastic waste in geosynthetic-reinforced flexible pavements has provided valuable insights into the feasibility and benefits of utilizing plastic waste in pavement construction. Through laboratory testing and numerical simulations, the mechanical properties, structural behavior, and environmental implications of plastic-modified pavements were thoroughly examined. The results of this study demonstrate that the incorporation of plastic waste can enhance the mechanical properties and performance of geosynthetic-reinforced flexible pavements. The plastic waste particles act as fillers, reinforcing the pavement matrix and improving its resistance to rutting and fatigue. This finding suggests that the integration of plastic waste can lead to more durable and longer-lasting pavements.the environmental assessments conducted in this study indicate that the incorporation of plastic waste in pavements can contribute to sustainability goals. The carbon footprint analysis reveals a reduction in the overall environmental impact of the pavement system, as the use of plastic waste reduces the demand for virgin materials. The leachate characterization tests demonstrate that the leaching potential of plastic-modified pavements remains within acceptable limits, ensuring minimal environmental contamination.The sustainable integration of plastic waste in geosynthetic-reinforced flexible pavements offers multiple advantages. Firstly, it provides a viable solution for recycling and beneficially reusing plastic waste, diverting it from landfills and reducing environmental pollution. Secondly, the improved performance and durability of plastic-modified pavements can lead to cost savings in terms of maintenance and rehabilitation.

REFERENCES

Madheswaran C. K, Gnanasundar G, Gopalakrishnan. N., “Effect of molarity in geopolymer concrete”, International Journal of Civil and Structural Engineering, 4.2., 106-115., 2013.

Manimaran E and Mohankumar G (2017) “Influence of Sodium Hydroxide Concentration on the Strengthof Fly ash Based GPC”, International Journal of Engineering Sciences &ResearchTechnology

Manju, R., Sathya, S., &Sheema, K. (2017). Use of plastic waste in bituminous pavement. Int J ChemTech Res, 10(08), 804-811.

Mashaan, N. S., Rezagholilou, A., &Nikraz, H. (2019, August). Waste Plastic as Additive in Asphalt Pavement Reinforcement: A review. In AAPA International Flexible Pavements Conference, 18th.

Mir, A. H. (2015). Use of plastic waste in pavement construction: an example of creative waste management. J Eng, 5(2), 57-67.

Mishra, B., & Mishra, R. S. (2015). A study on use of waste plastic materials in flexible pavements. International Journal of Innovative Research in Science, Engineering and Technology, 4(8), 6927-6935.

Moghaddam, T. B., Karim, M. R., &Soltani, M. (2013). Utilization of waste plastic bottles in asphalt mixture. Journal of Engineering Science and Technology, 8(3), 264-271.

P Kamhangrittirong, “The Effect of alkali Solution ratio and Curing Temperature on Properties of Flyash Based Geopolymer”, 33rd conference on our world in concrete & structures, 25 - 27 August 2008.

Patankar S.V, GhugalY.MandJamkar S.S, “Effect of Concentration of Sodium Hydroxide and Degree of Heat Curing on Fly ash Based Geopolymer Mortar,” Indian journal of materials science, vol. 2014, pp. 1–6, 2014.

Patel, V., Popli, S., & Bhatt, D. (2014). Utilization of plastic waste in construction of roads. International journal of scientific research, 3(4), 161-163.

Perkins, S. W., &Edens, M. Q. (2002). Finite element and distress models for geosynthetic-reinforced pavements. *International Journal of Pavement Engineering*, *3*(4), 239-250.

Phoo-ngernkham T, Hanjitsuwan S, Damrongwiriyanupap N, and Chindaprasirt P, “Effect of Sodium Hydroxide and Sodium Silicate Solutions on Strengths of Alkali Activated High Calcium Fly ash Containing Portland Cement,” KSCE Journal of Civil Engineering, vol. 21, no. 6, pp. 2202–2210, Oct. 2016.

Prasad, D. S. V., Raju, G. V. R. P., & Kumar, M. A. (2009). Utilization of industrial waste in flexible pavement construction. EJGE, 13(2), 207-211.

Rajasekaran, S., Vasudevan, R., &Paulraj, S. (2013). Reuse of waste plastics coated aggregates-bitumen mix composite for road application—green method. American Journal of Engineering and Research, 2(11), 1-13.

Rajmane, P. B., Gupta, A. K., & Desai, D. B. (2009). Effective utilization of waste plastic in construction of flexible pavement for improving their performance. OSR Journal of Mechanical and Civil Engineering, 2(17), 27-30.

Rajput, P. S., & Yadav, R. K. (2016). Use of plastic waste in bituminous road construction. International Journal of Science Technology & Engineering, 2(10), 509-513.

Ravindra N. Thakur and Somnath Ghosh., “Effect of mix composition on compressive strength and microstructure of flyash based geopolymer composites”, ARPN Journal of Engineering and Applied Sciences, 4., 68-74., 2009.

Rongali, U., Singh, G., Chourasiya, A., & Jain, P. K. (2013). Laboratory investigation on use of fly ash plastic waste composite in bituminous concrete mixtures. Procedia-Social and Behavioral Sciences, 104, 89-98.

Sandeep L.Hake, Dr R. M. Damgir and Dr S.V. Patankar, “State of Art- Investigation of Method of Curing on Geopolymer Concrete,” IOSR Journal of Mechanical and Civil engineering (IOSR-JMCE) e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 12, Issue 3 Ver. II (May. - Jun. 2015),