COMPARATIVE STUDY ON PENETRATION TEST OF BITUMINOUS AND WASTE PLASTIC MODIFIED BITUMEN

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Abstract

Aim: The aim of the research is to find out the hardness of the waste plastic bitumen by comparing the conventional bitumen and waste plastic modified bitumen using penetration test.
Materials and Methods: The sample VG-30/40 penetration grade bitumen was tested for the present study. The experiment contains two sample groups, each of which requires 25 samples and 50 sample tests are performed utilising G-power 0.8 with alpha and beta qualities are 0.05, 0.2 with a confidence interval at 95%. The Penetration test is performed by the waste plastic modified bitumen whereas the number of samples (N=25) and conventional bitumen were the number of samples (N=25).
Results: The waste plastic modified bitumen has 80 mm surface hardness of bitumen when compared to the conventional bitumen 68 mm. The study has a significance value of $p<0.05$ i.e. $p=0.026$.
Conclusion: The waste plastic modified bitumen outperforms conventional bitumen in penetration tests for performing the surface hardness

Keywords: Bitumen VG 30/40, waste plastic, modified bitumen, Low density polyethylene. plastic, Penetration test , penetration mould, benzene, glacier

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1. Introduction

Plastic (Polyethylene Terephthalate, PET) is now used as packaging material for a whole range of consumer products in addition to carbonated beverages. Although plastics are very useful products, the disposal of these wastes has become a problem and is of great concern, particularly in our country (Naskar, Chaki, and Reddy 2010). One of the solutions to the disposal of plastic wastes is recycling it into useful products such as it may be used in bituminous (asphaltic) pavements construction (Appiah, Berko-Boateng, and Tagbor 2017). The use of waste plastic for modifying the bitumen properties, which will be used for the road construction, has resulted in the reduction of the construction cost and eco-friendly disposal method of the waste plastic. Therefore using waste plastic in the construction of flexible pavement is an economical and eco-friendly method for the disposal of waste plastic (Köfteci, Ahmedzade, and Kultayev 2014). This study proposes novel waste plastic modified bitumen with conventional bitumen to determine the surface hardness of the (Hınıslıoğlu and Ağar 2004). The experimental results demonstrated that adding waste plastic improves the properties of bitumen across a range of loading frequencies and temperatures. This waste plastic modified bitumen mix shows better binding property, stability, stiffness, density and extra resistance to water. Bitumen is largely used to build flexible pavements, and when it is combined with plastic waste, the mix's water resistance, capacity, and stability are all improved (Aldagari, Kabir, and Fini 2022).

The Various reported works (Jamshidi and White 2019; Haider et al. 2020; Hake, Damgir, and Awsarmal 2020) proposed that plastic roads can be better as compared to normal bituminous roads in terms of surface hardness and pavement quality. IEEE Xplore published 174 research papers, and Google Scholar found 231 articles. Zoorab and Suparma 4 reported using recycled polymers that were mostly made of polypropylene and low density polyethylene in simple bituminous mixtures with better durability and fatigue life. In (Asare, Kuranchie, and Ofosu 2019; Santos et al. 2021), using waste plastic for asphalt modification could help reduce environmental contamination and reduce additional costs. Further, introducing waste plastic into asphalt will also improve the temperature susceptibility and stiffness. Thus, waste plastic-modified bitumen results in an enhancement in the rutting and fatigue resistance (Haider et al. 2020; Al-Haydari and Al-Haidari 2020; R. Kumar and Khan 2020). Mashaan et al. (N. Mashaan, Chegenizadeh, and Nikraz 2021; N. S. Mashaan et al. 2021) explored the prospect of utilising waste PET to enhance the engineering characteristics of the C320 bitumen binder and discovered encouraging outcomes. Williamson (Kassim and Williamson 2005) has reported that recycled polythene from grocery bags may be useful in bituminous pavements resulting in reduced permanent deformation in the form of rutting and reduced low-temperature cracking of the pavement surfacing. Vasudevan et al. (Vasudevan, Nigam, and Velkennedy 2010) stated that the polymer coated aggregate bitumen mix performs better for flexible pavements. Probably, the intermolecular bonding between waste polymer coated aggregate and bitumen enhanced the strength and quality of the bituminous mixes (Vasudevan, Nigam, and Velkennedy 2010). Awwad and Shbeeb (Awwad, Shbeeb, and Others 2007) investigated the results of the use of polyethylene polymers to improve the engineering properties of asphalt mixtures. Their study was conducted to determine the most optimum type of polyethylene and its proportion in an asphalt mixture to obtain the best properties.

Our institution is keen on working on latest research trends and has extensive knowledge and research experience which resulted in quality publications (Rinesh et al. 2022; Sundararaman et al. 2022; Mohanavel et al. 2022; Ram et al. 2022; Dinesh Kumar et al. 2022; Vijayalakshmi et al. 2022; Sudhan et al. 2022; J. A. Kumar et al. 2022; Sathish et al. 2022; Mahesh et al. 2022; Yaashikaa et al. 2022). The primary drawback of traditional bituminous (BC) is that it results in a variety of road pavement failures, including rutting, fatigue cracking, and cracking failures. Additionally, the cost of the entire project is significantly impacted by the rising price of bitumen. This study investigates the performance of bitumen modified by waste plastics and compares the results with conventional bitumen The main approach used to prevent the deterioration of pavements is improving the properties of materials used for constructing highways. Penetration tests were conducted to determine the surface hardness of the binder. The results showed that the waste plastic modified bitumen has lesser penetration values compared to the conventional bitumen

The uses of plastic waste help in substantially improving the abrasion and slip resistance of flexible pavement and also allow obtaining values of splitting tensile strength satisfied the specified limits while plastic waste content is beyond 30% by weight of mix. If the consistent mixing time and mixing temperature are not provided for bitumen– modifier mix, modified bitumen cannot exhibit good performance in situ, thus premature failures will occur. Therefore, there are certain recommended mixing times, mixing temperatures and modifier content for all the polymers with a trademark. This all should be taken in mind while mixing and laying of roads is to be done using plastic waste. The plastic

road would be a boon for India. In hot and extremely humid climates, durable and eco-friendly plastic roads are of greatest advantages. This will also help in relieving the earth from all types of plastic waste.

2. Materials and Methods

The study was conducted at the bitumen department of transportation engineering at the Saveetha School of Engineering, SIMATS, using the penetration test on waste plastic. The penetration grade VG-30/40 bitumen samples used in this study are bitumen samples. Waste plastic bags were used as a modifier in this study. The waste plastic was shredded into fibres of size 20mm x 3mm. Bitumen has waste plastic added at a rate of 5.0 percent. It involves two sample groups requiring 25 samples and 50 sample tests to be carried out for the experiment. Group 1 was conventional bitumen and Group 2 was novel waste plastic modified bitumen . The surface hardness of both the conventional bitumen and the novel waste plastic modified bitumen was assessed using the penetration test. The calculation is performed utilising G-power 0.8 with alpha and beta qualities 0.05, 0.2 with a confidence interval at 95 percent (Gawande et al. 2012).

Conventional bituminous

Bitumen is a binding material used in road construction. It is non-crystalline and dark brown in colour and has viscous properties. It is obtained from crude petroleum. In other words bitumen is any adhesive and solid mixture of hydrocarbons that are found naturally in tar, asphalt, mineral waxes, etc. used for constructing the road surface and roofing material It is mainly used for construction of roads, airport runways, car parking, footways etc. The grades of bitumen used for pavement construction are known as paving grades and those used for waterproofing of structures are known as industrial grades. The grade of straight run bitumen is chosen depending upon the climatic conditions of the region in which surface dressing is to be constructed. The conventional bitumen has the tendency to cause bleeding in the summer season on the road surface and may develop cracks in winters. Such bitumen has less bearing capacity and can cause damages because of higher axial load due to rapid increase in number of vehicles.

Waste plastic modified bitumen

Waste plastic modified bitumen is developed as one of the best construction materials used for the flexible pavement. It reduces medium and long term cost as the roads are less exposed to defects. This reduces maintenance cost, which is not only a financial problem but also a traffic problem as roads have to be closed for repairing or bituminous mix not only modify the properties of mix but also solve the problem of disposal of plastic and also creates employment to plastic collectors. The collected plastic waste was shorted as per the required thickness. Less micron plastic is easily mixable in the bitumen at higher temperature (160°C-170°C). It is clean by dusting or washing if required. Collected plastic pieces were sifted through 4.75mm sieve and retaining at 2.36mm sieve was collected. Firstly Bitumen was heated up to a temperature about 160°C-170°C which is a melting temperature. Pieces were added slowly to the hot bitumen of temperature around 160°C-170°C. The mixture was stirred manually for about 20-30 minute in that time period temperature was kept constant about 160°C-170°C. The hardness of bitumen which is used in road construction has been determined by the penetration test. Polymer bitumen mixture was prepared and used for carrying out penetration tests. It is a depth penetrated by the needle of a penetrometer into the bitumen sample under the specific condition. The penetration value is measured as one tenth of a depth penetrated by a needle. Consistency of bitumen is also evaluated through this test. In this test, the sample with 5 percent of waste plastic is prepared and penetration value is determined.

Statistical Analysis

For statistical implementation, the software tool used here is IBM SPSS V26.0 (Pallant 2010). The independent sample t test was performed to find the mean, standard deviation and the standard error mean statistical significance between the groups, and then comparison of the two groups with the SPSS software will give the accurate values for the two different parameters which will be utilised with the graph to calculate the significant value with maximum penetration value (68 mm), mean value (68) and standard deviation value (7.4152). Dependent variables are penetration tests and independent variables are conventional bitumen and waste plastic modified bitumen

3. Results

The penetration test of the 50 samples of both the groups were analysed using statistical tool SPSS version 21. Figure 1 The sample preparation and testing done is shown figure 2 shows the simple bar graph for conventional bitumen is compared with Waste plastic modified bitumen . The waste plastic modified bitumen is higher in surface hardness of 80 mm when compared with conventional bitumen 68 mm. There is a significant difference between conventional bitumen and waste plastic modified bitumen ($p<0.05$, independent sample test). X-axis: Waste plastic modified bitumen vs conventional bitumen Y-axis: Mean of penetration test of bitumen, for identification of keywords ± 1 SD with

95 % CI. Table 1. shows the comparison metrics for the penetration test findings for conventional bitumen and waste plastic modified bitumen of 10 samples each group. Conventional bitumen has a surface hardness of 68 mm, whereas waste plastic modified bitumen has a surface hardness of 80 mm. Waste plastic modified bitumen outperforms conventional bitumen in all elements of the penetration test. Table 2. shows the statistical calculations for conventional bitumen and waste plastic-modified bitumen, such as the mean, standard deviation, and standard error mean. The t-test employs the penetration test. The mean penetration test for regular bitumen is 68 mm, while the mean penetration test for bitumen modified with waste plastic is 80 mm. Conventional bitumen has a standard deviation of 4.0454 while waste plastic modified bitumen has a standard deviation of 7.4152. Conventional bitumen has a standard error mean of 1.2382, while waste plastic modified bitumen has a standard error mean of 2.3750. Table 3. displays the statistical analysis for independent samples comparing waste plastic modified bitumen to conventional bitumen . The significance threshold for the penetration test is 0.026. Using an independent sample T-test with a level of significance of 0.53626, a comparison between regular bitumen and waste plastic modified bitumen is made. This independent sample test includes lower and upper interval difference, mean difference, standard error difference, significance as 0.20, significance (2-tailed), and significance.

4. Discussion

This proposed study reveals how waste plastics can be used efficiently for road building and repair, resulting in better, more durable, and more sustainable roadways. The penetration test determines the hardness or softness of bitumen by measuring the depth in tenths of a mm to which a standard loaded needle will penetrate vertically in 5 seconds. This test is used for evaluating consistency of bituminous materials. This proposed waste plastic modified bitumen mix can be suitably used in hotter climatic conditions, especially in the regions where temperature differential is substantially higher. This proposed method helps the pavements to resist higher temperature by minimising the formation of cracks and reducing rainwater infiltration which otherwise leads to the development of potholes. These waste plastics modified bitumen pavements have shown improved crushing and abrasion values and reduced water seepage. The results showed that the waste plastic modified bitumen mix had a penetration of 68 mm, which was lower than the penetration of the conventional bituminous mix sample, which was 80 mm. The experimental findings also show that the addition of waste plastic makes the modified bitumen harder and more consistent than plain bitumen which results in improvement in the rutting resistance of the mix.

Some similar studies were made by Kumar and Garg (P. Kumar and Garg 2011) investigated rheology of waste plastics-fibre bitumen. They found that the properties of bitumen such as penetration, softening point and ductility were improved with the addition of the waste fibre. Also the optimum ratio of the fibre was found to be 0.5% on the basis of PG (Performance Grade) 70 in this study. Ranadive and Tapase (Ranadive and Tapase 2012) conducted an experimental program to study the improvement in the strength of flexible pavement, by adding plastic waste in different percentages. The authors observed that 10% of bitumen can be replaced by plastic waste in the bituminous layer. Rokade (Rokade 2012) studied the use of plastic waste and waste rubber tyres in flexible pavements.

The Semi Dense Bituminous (SDBC) was prepared by penetration method using VG-30 grade bitumen and the various mix design characteristics were calculated. In 2019, Agyeman et al. (Agyeman et al. 2019) conducted a succession of laboratory tests on different waste plastic materials from various industrial sources in the probable use of road construction materials like paver blocks, etc. The results indicate that both low and high plastic specimens had better penetration value as compared to a non-plastic specimen.

The drawback of the proposed waste plastic modified bitumen is that as the amount of fibres increases, the 's workability declines. Future research should examine the use of various bitumen kinds, blending circumstances (in terms of duration, temperature, and shear velocity), and various waste plastic diameters, shapes, and blend rates. For a better understanding of the engineering features, it is also necessary to use cutting-edge technology to investigate the chemical transformation in the waste plastic modified bitumen interaction phase

5. Conclusion

In this research, the penetration test was carried out using both conventional bitumen and modified bitumen with waste plastic. The proposed waste plastic modified bitumen has obtained the lower surface hardness of bitumen values in comparison to conventional bitumen 68 mm Waste plastic modified bitumen has surface hardness bitumen of 80 mm in the penetration test, which is better than the surface hardness bitumen of conventional bitumen , which is 68mm. There is a significant decrease in penetration values for modified blends, indicating the improvement in their temperature susceptibility resistant characteristics.

Declaration

Conflicts of Interest
No conflict of interest in this manuscript

Authors Contributions
Author RR was involved in data collection, data analysis, manuscript writing. Author DK was involved in conceptualization, data validation, and critical review of the manuscript.

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Tables and Figures

Table 1. The comparison metrics for the penetration test findings for conventional bitumen and waste plastic modified bitumen of 25 samples each group. Conventional bitumen has a surface hardness of 68 mm, whereas waste plastic modified bitumen has a surface hardness of 80 mm. Waste plastic modified bitumen outperforms conventional bitumen in all elements of the penetration test.

S.No	Conventional Bitumen (mm)	Waste Plastic Modified Bitumen (mm)
1	50	72
2	53	73
3	55	65
4	54	63
5	57	60
6	52	67
7	53	76
8	56	77
9	58	70
10	59	71
11	60	68
12	61	69
13	65	64
14	63	63

15	67	78
16	58	76
17	50	75
18	63	69
19	65	70
20	66	72
21	62	84
22	67	87
23	64	84
24	60	82
25	68	80

Table. 2. The statistical calculations for conventional bitumen and waste plastic-modified bitumen , such as the mean, standard deviation, and standard error mean. The t-test employs the penetration test. The mean penetration test for regular bitumen is 68mm, while the mean penetration test for bitumen modified with waste plastic is 80mm. Conventional bitumen has a standard deviation of 4.0454 while waste plastic modified bitumen has a standard deviation of 7.4152. Conventional bitumen has a standard error mean of 1.2382, while waste plastic modified bitumen has a standard error mean of 2.3750.

Group		N	Mean	Standard Deviation	Standard Error Mean
Penetration Test	Conventional bitumen	25	68	4.0454	1.2382
	Waste Plastic Modified Bitumen	25	80	7.4152	2.3750

Table 3: The statistical analysis for independent samples comparing the waste plastic modified bitumen to conventional bitumen has been presented. The significance threshold for the penetration test is 0.026. Using an independent sample T-test with a level of significance of 0.53626, a comparison between regular bitumen and waste plastic modified bitumen is made. This independent sample test includes lower and upper interval difference, mean difference, standard error difference, significance as 0.20, significance (2-tailed), and significance.

Group		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval (Lower)	95% Confidence Interval (Upper)
Penetration Test	Equal variances assumed	3.231	0.026	-4.413	45	.20	-1.12680	.53626	-5.88525	-.43115
	Equal variances not assumed			-4.413	48.07	.020	-1.22680	.53626	-5.08345	-.43160

Fig 1: Sample Preparation and Testing of penterention test

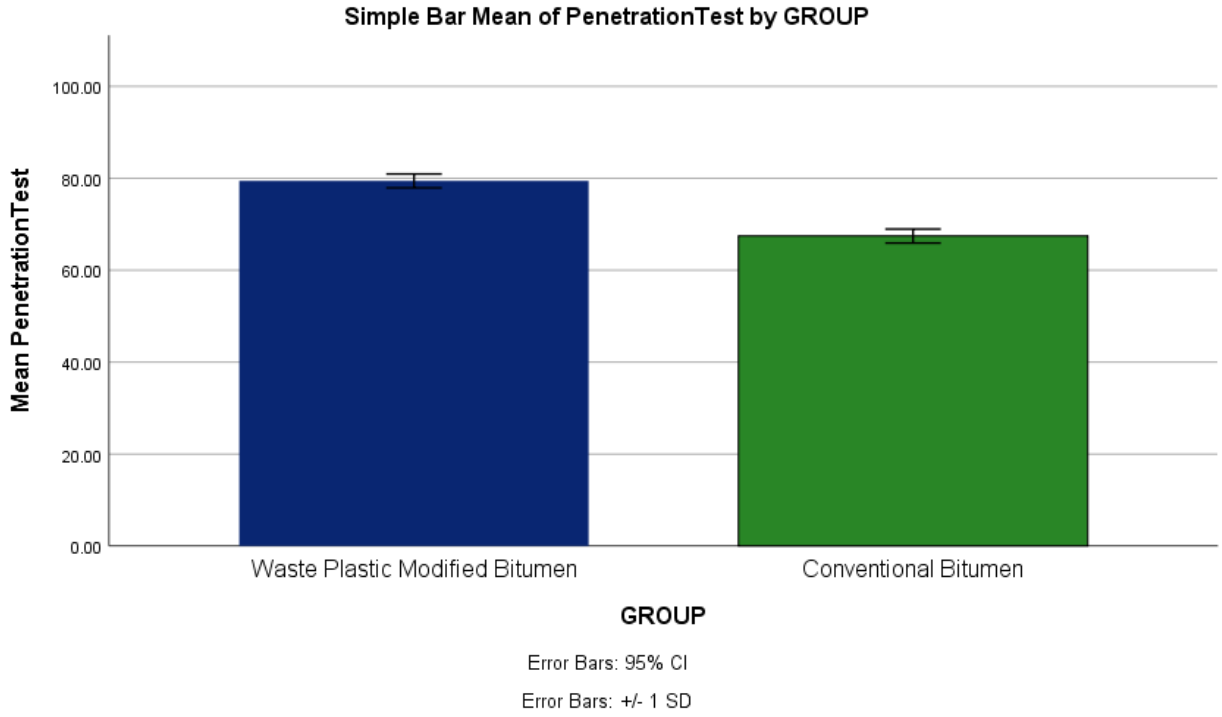

Fig. 2. Simple bar graph for conventional bitumen is compared with Waste plastic modified bitumen . The waste plastic modified bitumen is higher in surface hardness of 80 mm when compared with conventional bitumen 68mm. There is a significant difference between conventional bitumen and waste plastic modified bitumen ($p<0.05$ Independent sample test). X-axis: Waste plastic modified bitumen vs. conventional bitumen Y-axis: Mean of penetration test, for identification of keywords ± 1 SD with 95 % CI.