An Experimental Analysis of Using Steel Slag and Plastic in Dense Bituminous Macadam

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***Abstract*— This investigation mainly aims of reusing plastic waste, specifically LDPE (low-density polyethylene) as well as BOF steel slag, thereby decreasing the overall construction cost of roads and resolving the problem of solid waste management. The LDPE waste plastic of exactly 5.16% by weight of optimum bitumen content is mixed with the bitumen VG 30 of 60/70 penetration grade (grade most commonly used in the state) and performing softening point test, penetration, and ductility test. The percentage of bitumen content used in each of the three samples is 4.25%, 4.50%, and 4.75% by weight of total aggregate. In this analysis, Steel slag, specifically basic oxygen furnace BOF in the aggregate form, was used in the percentage of 10%, 15%, and 20% by total weight conventional aggregate. A mix design of DBM Grade II is prepared according to Indian standards and performs a gradation test (sieve analysis), water absorption test, and specific gravity test of the aggregate. The asphaltic mix of a modified specimen is tested with the Marshall stability and flow test and compared with the unmodified one. The analysis found out to be a maximum increase of stability value at binder content @4.5% and steel slag @15% by 2.4% of the unmodified mix with a corresponding increase in its flow value by 3.65%. this shows the mix is considerably more resistant to rutting, distortion, and overall stability of the pavement.**

***Index Terms*— Bitumen, dense bituminous macadam, low-density polyethylene, steel slag.**

I. INTRODUCTION

Plastic waste management has become the most crucial among other solid waste. Also, the cost of recycling plastic is much more than making it from the scratch. The adverse influences of littered single-use plastic objects plastic on terrestrial and aquatic ecosystems, such as within marine surroundings are globally identified. For a single unit of plastic. Low-density plastic is mainly translucent, resistant to chemical attack, semi-rigid, weatherproof, low water absorption, cheap and easy to manufacture, and can be easily recycled The large technology of plastic waste in India is due to speedy urbanization, unfold of retail chains, plastic packaging from grocery to meals and vegetable merchandise, to cosmetics and client objects. Steel slag nowadays has been largely employed in civil engineering works such as road engineering as it has a rough surface. Specifically speaking, BOF Steel slag chemically comprises of CaO:35–45%, SiO_2:12–17%, Al2O3: 0.98–3.4%, FeO: 10–25%, MgO: 3–15%, MnO: 5–15%, SO_3 : 0–0.3%, P2O5: 0.2–4%. For steel slag to be used as aggregate shows good abrasion resistance, good soundness characteristics, and high bearing strength that's why it can be used as an effective replacement at the optimum percentage of the conventional aggregate in pavement construction work. Steel slag can easily be made workable with the bituminous mix infused with waste plastic & can effectively be utilized to strengthen flexible pavement. The utilization of metal slag aggregates in asphalt combination has come to be the focus of researchers' interest due to the advanced performance of the asphalt mixtures incorporating steel slag aggregates. Approximately 2-4 tonnes of steelmaking slag is produced when manufacturing one ton of steel in an integrated steel plant. Bitumen is used in many experiments in various research projects which have shown effective results when incorporated with plastic. As a result of the experimentation, researcher Alnadish et al., (2021) found that the asphalt mixes incorporated coarse steel slag combination exhibited first-rate overall performance in comparison with the other substitutions in phrases of the resilient modulus and fatigue resistance. Also, the results in some investigations were similar to the regular aggregate.

The end result shows that the metal slag has an honest resistance to fragmentation and wear Sorlini et al., 2019.

II. LITERATURE REVIEW

A. Adham Mohammed Alnadish (2021) evaluated the Fiber-Modified Asphalt Mixtures Incorporating Steel Slag Aggregates in a laboratory. At the end of the experimentation, it was concluded that the asphalt mixes infused with coarse steel slag combination exhibited first-rate overall performance in comparison with the other substitutions in phrases of the resilient modulus and fatigue resistance. While the asphalt mixes incorporating 100% of metallic slag aggregates exhibited the worst overall performance.

B. Sabrina Sorlini (2019) reused the EAF steel slag in bituminous paving mixtures. The consequences of exams done on bituminous combinations with EAF slag were similar to the overall performance of combinations containing regular aggregates and the leaching assessments supplied high-quality effects. The end result shows that the metal slag has an honest resistance to fragmentation and wear.

C. Ahmed Ebrahim (2012) evaluated the usage of steel slag and crushed limestone mixtures as sub-base materials in flexible pavement. The outcomes indicated that the mechanical characteristics and the resistance elements were stepped forward by way of adding EAF steel slag to the crushed limestone. Increasing the steel slag percentage (SSP) to the limestone inside the combined blend will increase the mechanical houses such as most dry density, California Bearing Ratio and resilient modulus.

D. Liu Chunlin (2011) assessed the possibility of Concrete Prepared with Steel Slag as Fine and Coarse Aggregates in a Preliminary Study. The author further concluded that the strong performance of EAF slag concretes is similar to that of extra conventional concrete, with higher compressive electricity and barely much less flexural electricity.

E. Sevil Köfteci (2016) evaluated the performance of bitumen modified by various types of waste plastics. With all the facts considered, it was concluded that within the modification of natural bitumen with waste PVC substances, high-quality results had been obtained with the waste window-based components and that the most efficient ratio for this additive became 3%.

F. Melkamu Birlie Genet (2021) Investigated waste LDPE plastic as a modifier of asphalt mix for highway asphalt on Ethiopian roads. Marshall Test Method was used to determine the optimum bitumen content and to evaluate the marshal properties of the plastic-modified asphalt mix. The OBC of the non-modified marshal sample was found to be 5.16% by weight of the total aggregate while the optimum waste LDPE-modified bitumen content was found to be 6.5% by weight of the OBC. Asphalt mix modified with 6.5% waste LDPE plastic content has a 33.67% higher stability value compared to the non-modified asphalt mix.

III. MATERIAL AND METHODOLOGY

Material.

The bitumen used as a binder in the asphaltic mix is VG30 having a penetration grade of 60/70 as per IS code 73:2006. Conventional Stone Aggregate (gravel) is available in different sizes i.e. 20mm, 10mm, and 6mm, and dust mixed under the limit specified by the IS code for DBM (dense bitumen macadam) grade II. The aggregate has been sourced out from the institute itself i.e. SSTC, Bhilai campus. Grading-2 is suitable for the layer thickness of 50 mm to 75 mm and a 26.5 mm nominal size of aggregate shall be used. The 2% mineral filler added in the bituminous mix is taken to be cement. Waste LDPE Plastic of about 5-10 mm in size which is collected from a local vendor is cleaned and processed. The particular type of steel slag employed in this experimentation is basic oxygen furnace BOF steel slag in the form of aggregate which is sourced from the Bhilai Steel Plant (BSP), Bhilai.

Fig 1. LDPE

Methodology.

The modified and unmodified asphaltic mix is prepared according to the mix design of dense bituminous mix grade II. A total of nine mixes prepared were unmodified and the other nine mixes are modified with LDPE Plastic @5.16% of binder content Genet et al., 2021 and BOF steel slag @ 10%, @15%, and @20% by weight of total aggregate. For the modified samples the LDPE plastic is first mixed with the hot bitumen carefully at a specified percentage than mixed with the sieved aggregate along with the steel slag (at a specified percentage) as per the design norms of dense bituminous macadam, grade II for further testing.

Fig. 2 BOF steel slag in aggregate form

IV. EXPERIMENTATION ANALYSIS

The grade of bitumen VG 30 used in this test is tested with the penetration test, softening point test, and ductility test in the laboratory. The aggregate employed in this experiment, water absorption, and specific gravity is found out as well as for steel slag.

The melting point of 5-10 mm processed LDPE is noted down. A gradation test is performed for aggregate. A design mix according to the dense bituminous macadam, grade 2 is prepared and mould is prepared for testing Marshall stability test and flow test for modified and unmodified specimens.

Penetration test. The penetration test of bitumen measures the hardness or softness of bitumen by using the measure of the intensity of penetration of a widespread loaded needle in five seconds whilst maintaining the bitumen pattern temperature at 25 °C. A penetrometer together with a needle meeting with a complete weight of one hundred grams and a tool for freeing and locking the needle in any position. To read the penetration value, a graduated dial is hooked up as proven. Penetration value can be studied with this dial as much as 0.1 mm. A flat-bottomed cylindrical steel dish 55 mm in diameter and 35 mm extensive is required. If the penetration is of the order of 225 or greater, a dish of 70mm diameter and 45mm depth is required.

Softening point test. The softening point of bitumen or tar is the temperature at which the substance attains a precise degree of softening. According to IS: 334-1982, ASTM E28-67 or ASTM D36, or ASTM D6493 – 11. The apparatus of it consists of Steel balls-two in number each of 9.5 mm diameter weighing 3.5 ± 0.05 g. also, Brass earrings-two numbers every having depth of 6.4 mm. The internal diameter at the bottom and pinnacle is 15.9mm and 17.5 mm respectively. Ball guides to manually the motion of steel balls centrally. Support -which can maintain rings in position and additionally lets in for suspension of a thermometer. The distance between the lowest of the earrings and the top floor of the lowest plate of the support is 25mm. Thermometer that may study as much as a hundred° C with an accuracy of 0.2° C. Bath-heat resistant glass beaker not much less than 85 mm in diameter & 1220 mm deep and a Stirrer.

Ductility test Ductility is the measure of the property by which bitumen can be made into thin wire. It is expressed as the distance in cm to which a standard briquette of bitumen can be stretched before the thread breaks. The test is conducted at 27 degree Celsius and at a rate of a pull of 50mm/minute. Mould is made up of brass and has the dimension of a total length of 75mm, a thickness of around 10mm, a distance between clips 30 mm, a water bath containing a thermostat maintained at +/-0.1 degree Celsius the temperature of specified test temperature containing water at least 10 liters immersed in water at a depth of at least 100 mm.

Sieve analysis This is the basic test done for aggregates to achieve the specified gradation hence also called the gradation test. it determines the distribution of aggregates according to their sizes in order to prepare a mix of a specified grade. An acknowledged weight of the material, the amount is determined with the aid of the largest size of aggregate, is placed upon the top of a set of nested sieves (the top sieve has the biggest display openings and the display beginning sizes lower with every sieve all the way down to the lowest sieve which has the smallest commencing size display for the type of fabric special) and shaken via mechanical means for a time period. After shaking the fabric through the nested sieves, the material retained on each of the sieves is weighed. Percentage cumulative weight is then found out of each IS sieve from top to bottom.

Marshall stability test and flow test. This test has been extensively used for flexible pavements (ASTM D1559. IRC 111:2009). It gives the value of Marshall stability value which is defined as the maximum load taken by the compacted specimen at the standard

Table 1. Composition of dense bituminous macadam

Grading	1	2
Nominal aggregate size	37.5 mm	26.5 mm
Layer thickness	75-100 mm	50-75 mm
IS Sieve (mm)	Cumulative % by weight of total aggregate passing	
45	100	-
37.5	95-100	100
26.5	63-93	90-100
19.0	-	71-95
13.2	55-75	56-80
4.75	38-54	38-54
2.36	28-42	28-42
1.18	-	-
0.6	-	-
0.3	7-21	7-21
0.15	-	-
0.075	2-8	2-8
Bitumen content % by mass of total mix	Min 4.0	Min 4.5

temperature with respect to which flow value is also determined. This test was also used to find out the optimum bitumen content of the binder used. The test method consists of a cylindrical specimen mould (diameter 10cm, height 7.5cm) assembly in which the suitable mix design is filled and compacted while keeping the mould over the com-paction pedestal (20x20x45 cm) wooden block with the load of 4.5 kg free fall from the height of 47.5cm each side 75 blows of the specimen using compaction rammer. Specimen extractor for extracting the specimen from the mould. The mould is left undisturbed for 24 hours straight after which the weight of the specimen in water is noted. Then leaving the specimen inside water for 30 minutes at 60 degrees Celsius after which the weight of the specimen is taken in the air (which is called surface saturated dry weight). The specimen then is kept in the breaking head and deflection and load are noted down. Marshall stability value is thus obtained when maximum load is indicated between the deflection 2-5mm. flow value is the value shown at maximum stability value.

V. RESULT

The bitumen grade VG30 having Absolute viscosity at 60°C, 2400-3600 Poises according to the IS 1206 PART 2. The tests of ring and ball for softening point, ductility test and penetration test performed in the unmodified sample of bitumen according to the Indian standard procedures.

Table 2. Bitumen Test Report

S.no.	Test description	Value	IS code
1.	Mean Penetration value	64	IS 1203
2.	Ductility value (cm)	97	IS 1208
3.	Mean softening point (°C)	49	IS 1206

As per IS 2386 part 3 1963, the water absorption test and bulk specific gravity test performed for steel slag found to be 3.09 and 4.179% respectively.

In Marshall stability and flow test of modified mould is found out to have maximum value of stability at steel slag 15% by total weight of aggregate when binder content 4.5% and plastic LDPE content @5.16% by weight of bitumen. The Table-3 and Table-4 depicts the Marshall mould test result of unmodified and modified respectively.

Calculations.

A. Bulk specific gravity of mix (G_m)

$$G_m = W_m/W_s-W_w$$

Where W_w is the weight of the mould in water, W_s being weight in air in saturated surface dry and W_m is the weight in air.

B. Theoretical density (G_t)

$$G_t= (W_1+W_2+W_3+W_b)/(W_1/G_1+W_2/G_2+W_3/G_3+W_b/G_b)$$

Where W_1 and G_1 being weight and apparent specific gravity of coarse aggregate in the total mix, W_2 and G_2 being weight and apparent specific gravity of fine aggregate in the mix, W_3 and G_3 are the weight and apparent specific gravity of the filler material and W_b and G_b are the weight and apparent specific gravity of the binder or bitumen.

C. Air void percent (V_v)

$$V_v = (G_t-G_m)100/G_t$$

D. Percentage volume of bitumen (V_b)

$$V_b =G_m.W_b/G_b$$

E. Voids in mineral aggregate (VMA)

$$VMA = V_v + V_b$$

Table 3. Marshall mould test for DBM conventional Asphaltic mix

Binder content (%)	4.5%		
Weight in air(gm)	1235.5	1238.0	1233.5
Weight in water (gm)	719.0	722.0	719.5
Weight in air SSD (gm)	1240	1242.5	1238.5
Volume (cc)	521.0	520.5	519.0
Density (G_m) (gm/cc)	2.371	2.378	2.377
Average density (G_m)	2.376		
Theoretical specific gravity (G_t)	2.497		
Void in mineral aggregate VMA(%)	16.781		
Air void (V_v)(%)	4.487		
Voids filled bitumen VFB (%)	71.115		
Stability measured (KN)	14.12	14.25	14.28
Correction factor	0.96	0.96	0.96
Corrected stability (KN)	13.56	13.68	13.71
Average stability (KN)	13.65		
Flow (mm)	3.62	3.48	3.57
Average flow (mm)	3.56		

F. Voids filled with bitumen (VFB)

$$VFB = V_b.100/VMA$$

Table 4. Marshall mould test for DBM grade 2 modified Asphaltic mix

Steel slag content (%)	15%		
Binder content (%)	4.25%	4.50%	4.75%
Weight in air(gm)	1261.2	1276.7	1286.3
Weight in water (gm)	743.2	769.3	780.2
Weight in air SSD (gm)	1275	1283.2	1292.6
Volume (cc)	531.8	513.9	512.4
Density (G_m) (gm/cc)	2.371	2.489	2.540
Theoretical specific gravity (G_t)	2.491	2.599	2.686
Void in mineral aggregate VMA (%)	16.897	17.650	20.745
Air void (V_v) (%)	4.817	4.230	5.435
Voids-filled bitumen VFB (%)	71.491	76.033	73.800
Stability measured (KN)	13.66	13.98	12.03
Correction factor	0.96	1	1
Corrected stability (KN)	13.11	13.98	12.03
Flow (mm)	3.26	3.69	3.59

The result above shows the maximum value for 15% BOF Steel Slag for the Marshall stability and flow value. Therefore, the value of optimum bitumen content for the unmodified & modified mix has to be taken from it. Thus, the average optimum binder content was found out to be 4.416% of the unmodified mold while for the modified mold it was found to be 4.5% which is a bit greater than the unmodified ones.

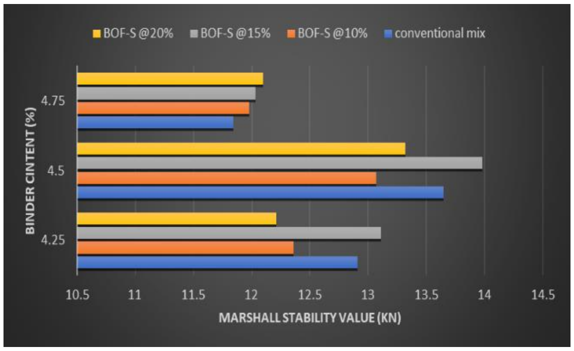

Fig.3 Comparison graph between modified and unmodified for Marshall Stability value.

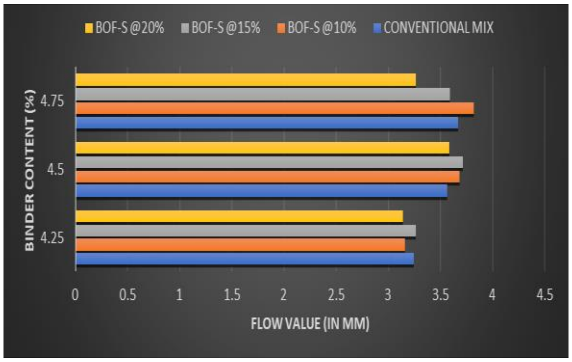

Fig.4 Comparison graph between modified and unmodified for Flow value

VI. CONCLUSION

Marshall stability appropriately signifies the resistance to distortion, shearing stresses, rutting, and displacement of the asphaltic mould mixes. The value comprises mainly the internal friction and cohesion between the particles of the bituminous mix which comes from the binding force of the binder and interlocking of aggregates. And the flow value determines the flexibility of the mix. The more the flow value the more flowy and flexible is the mix. The following are the conclusion drawn from the experimentation.

A. By the addition of LDPE plastic and BOF steel slag at the rate of 5.13% and 15% respectively, there is slight increase of optimum binder content by 1.902% of the Marshall modified mould.

B. The very fact that slightest increase in OBC nearly indicates the more of the binder material has been absorbed by the aggregates and the steel slag present among the mix which may be due to the addition of the steel slag.

C. The Marshall stability test of modified mix gives maximum value of stability value when the steel slag is added about 15% of the total aggregate which is about 2.4% more than the conventional mix according to the mix design of DBM grade 2.

D. The fact is clear from this investigation that the addition of steel slag and LBPE has considerably increased the shear stress and distortion resistance capacity of the dbm in the binder course, thereby reducing the risk of rutting caused due to repeated heavy loading of wheel load.

E. The value of stability value has abruptly decreased at 20% by steel slag which was concluded to be uneconomical for further addition of it.

F. The average flow value corresponding to the maximum stability value of the modified mix (MAM) (BOF steel slag @15%) increased very narrowly by about 3.65% when compared to the conventional mix.

The factual description highlighted from the experimentations further concluded that the use of waste LDPE plastic and steel slag not only improvises and enhances the properties of the DBM but also sorted the ways in which these wastes can prove to be useful in the construction industry through civil engineering. Bitumen changed by LDPE seems to enhance the property of bituminous mix at the same time making the overall construction cost more economical than the flexible pavement. To some extent, it may also solve the problem of solid waste management and the problem of plastic littering in the environment as most of the LDPE plastic used in this investigation is carrying bags.

VII. FUTURE SCOPE

More of research work needs to be done in this field further with more trials. Slags have been in huge demand for the construction industry due to the fact that it has non-reactive, stable, and blend really well with the regular aggregate which is a huge advantage for us. However, many researchers have already concluded its usefulness in their research studies. Also, there is a need to investigate on a large scale and chemically with such a combination of BOF steel slag and LDPE plastic. In-depth studies and discussions must be made in this regard globally to make use of it in a full-fledged way.

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