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INFLUENCE OF BOF STEEL SLAG AND WASTE LDPE PLASTIC IN FLEXIBLE PAVEMENT

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Abstract

This investigation typically objects to reprocessing plastic waste, particularly LDPE (low-density polyethylene) in addition to BOF metal slag (BOF-S), thereby reducing the overall production value of avenue and resolving the trouble of solid waste management. The outcomes accordingly evaluated from the experimentations observed out to be noticeably high quality and significant. The LDPE waste plastic of precisely 5.16% by using the weight of most efficient bitumen content is mixed with the bitumen VG 30 of 60/70 penetration grade (grade maximum typically utilized in Chhattisgarh) and appearing softening point test, penetration, and ductility test. The percentage of bitumen content material used in each of the three samples is 4.25%, 4.50%, 4.75% by weight of the overall combination. In this analysis, Steel slag, primarily basic oxygen furnace BOF inside the combination shape, is utilized in the share of 10%, 15%, and 20% through overall weight conventional combination. A mix design of DBM Grade II is ready in keeping with Indian standards and performing gradation check (sieve analysis), water absorption check, and particular gravity check of the aggregate. The asphaltic blend of a changed specimen is tested with the Marshall balance and goes with the flow test in comparison with the unmodified one. The analysis determined out to be a maximum in-crease of stability value at binder content @4.5% and metallic slag @15% by 2.4% of the unmodified mix with a corresponding increase in its waft price by means of 3.65%. This suggests the mix is substantially extra resistant to rutting, distortion, and multiplied stability.

Keywords: *Bitumen; LDPE; Steel slag.*

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1. 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 each terrestrial and aquatic ecosystems, such as within marine surroundings are globally identified As a single unit of plastic The large technology of plastic waste in India is due to speedy urbanization, unfolding of retail chains, plastic packaging from grocery to meals and vegetable merchandise, to cosmetics and client objects.

Steel slag has nowadays been largely employed in the civil engineering works such as in road engineering as it has rough surface Steel slag is something that can easily be made workable with the bituminous mix which is 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 used in many experimentations in various research projects in which has shown effective results when incorporated with plastic.

1.1 Plastic waste in India

It is a non-biodegradable material which is a huge concern when it comes to solid waste management. The plastic which has no use and has been discarded is called plastic waste. Plastic waste creates littering problems in surroundings, pollution in the environment & nuisance for animals as well as aquatic beings It is a non-biodegradable material which is a huge concern when it comes to solid waste management. The plastic which has no use and has been discarded is called plastic waste. Plastic waste creates littering problems in the surroundings, pollution in the environment & nuisance for animals as well as aquatic beings. Chemically, LDPE is mainly inactive when it comes to reacting with chemicals like diluted acids, diluted bases, oil & grease, alcohol, and hydrocarbons. Physically speaking it has high impact strength in low temperatures, high melting point, and electrical insulation.

1.2 Steel Slag

Steel slag being the byproduct of steel industries categorized into basic oxygen furnace (BOF) steel slag, Electric arc furnace (EAF) steel slag, Ladle slag produced on the different stages on the multiple level of steel generation. Typically, BOF slag contains approximately 10–20% $SiO2$, 40–50% CaO, 10% MgO, 15–20% iron (mixed oxides), 2–5% $Al2O3$, 10% manganese oxide (MnO), and other oxides. Iron oxides content depends on carbon levels attained in the metal; it generally increases with lower carbon levels. For EAF slag, an oxidizing slag may contain 40–50% CaO, 12–20% $SiO2$, 5–35% iron (mixed oxides), 3–10% $Al2O3$, 2–12% MgO, and 5–15% MnO. Typical reducing slag may contain 55–70% CaO, 15–25% SiO, 1–3% $Al2O3$, 3–12% MgO, and 0.5–2% FeO and MnO. Talking about physical characteristics the bulk specific gravity of the steel slag found to be 3.2-3.6 and water absorption about 3%. In mechanical terms, for steel slag to be used as aggregate shows good abrasion resistance, good soundness characteristics, and high bearing strength.

Presently, this Steel Slag is not applied and is dumped on the high-priced land to be had near the vegetation. The disposal of Industrial Waste is becoming a very huge problem and business waste is increasing every day. Now It is a necessity to apply the steel slag waste through technical development in every area. Its disposal inflicting excessive fitness and environmental dangers in road creation industries is progressively gaining tremendous importance in India thinking about the disposal, environmental problems and slow depletion of natural sources like soil and aggregates.

1.3 Steel Slag and LDPE incorporated in Bituminous Mix

Steel slag can easily be made workable with the bituminous mix infused with waste plastic & can effectively be utilised to strengthen flexible pavement. Bitumen used in many experimentations in various research projects in which have shown effective results. In this investigation, bitumen VG 30 having 60/70 penetration grade using of which twelve samples were prepared by gradually adding plastic in the hot bitumen, percentage of 5.16% by weight of bitumen [1] in which three samples are free from any adulterations. The mix kept at the continuous stirring at high temperature to maintain uniform viscosity of the mix. Before addition of plastic into the asphaltic mix conventional tests of bitumen were performed such as penetration test, ductility test, softening point test and viscosity test to compare it with the standard values. This can be done by simply comparing the result of the tests performed for normal bitumen (without plastic) to that of the plastic modified bituminous mix. The result showed that when plastic is added in the bitumen at optimum quantity, there is increase in softening point, decrease in the penetration value and ductility value [2]. Also, the viscosity has to increase. After addition of LDPE plastic in the bitumen, the steel slag is further added at the percentage of 10%, 15% and 20% by weight of total aggregate weight as a filler material to make the mix effectively workable, strong and more durable so that it can be used to conceal all the failures in the flexible pavement [3]. The researches that are carried out with the steel slag used with asphalt have showed the improved properties of the entire mix & relatively better strength as compared to conventional asphaltic mixes [4]. Thus, using optimum quantity of plastic with the steel slag with the bitumen tends to impart more strength and durability that will be capable of resisting heavy wheel load, wear and tear of the pavement and securing potholes more effectively.

2. LITERATURE REVIEW

Numerous studies have been done in the field of enhancing quality of flexible pavement in which slag and waste plastics were employed. This can be evaluated by field as well as laboratory experimentations conducted. At the end of the studies many researchers concluded to have found the promising result in this regard. Some of them were well discussed here including with their conclusions in the end.

(I) Rahul Kumar (2020) analyzed the Use Of Steel Slag in Flexible Pavement. In his study, he found that when the local soil and steel slag blend with the boom in metallic slag content material there is an growth in MDD with the corresponding decrease in OMC. High precise gravity and maximum dry density of slag in comparison to nearby soil may be due to high percent of iron oxide found in the slag. Slag became located to be fantastically crushable while soil become non crushable. When generated slag is being rolled via a roller, it's far determined that gravel size fabric gets chaned to sand size cloth. The cloth is also observed to be porous as indicated with the aid of moisture absorption test.

(II) Wenhuan Liu (2020) conducted a study to investigate the Interfacial Adhesion Performance and Mechanism of a Modified Asphalt–Steel Slag Aggregate. The mechanism of adhesion between the asphalt and metallic slag combination became analysed from the perspectives of bodily adsorption and chemical reactions. An FTIR infrared spectrometer become used to discover the interactions between the asphalt and metallic slag. Also, DSR (Dynamic Shear Rheological) test. In the end of his study he gathered that the asphalt contained alkane, cycloalkane, carboxylic acid, ester, amide, aliphatic amine, fragrant ether, sulfoxide, and other practical compounds, of which some (along with carboxyl) had been hydrophilic useful groups. As a end result of the experiments performed, the contact situations among the asphalt and metallic slag have been unique than those between asphalt and limestone. After the asphalt become embedded within the mixture surface to a sure intensity, its strain location elevated, significantly enhancing its resistance to outside forces.

(III) Aiqin Shen (2018) analysed the mechanism of adhesion property between steel slag aggregate and rubber asphalt using the test pull-out test and net adsorption tests were applied to compare the adhesion between distinctive aggregates and rubber asphalt. The morphology of different aggregates and the microstructure of aggregate-asphalt interface transition zone were observed using scanning electron microscopy (SEM). Moreover, Fourier Transform Infrared (FTIR) Spectrometer turned into implemented to study the chemical reaction mechanism among metal slag and rubber asphalt. As a result, the size of metallic slag and the mixing time of asphalt have little impact on the adhesion of asphalt with metal slag. Based at the SEM test, there are numerous pore shape and coralline debris on the floor of metallic slag, the asphalt can fill the micro-pore shape at the floor of the metal slag aggregates, and it will form a positive embedding intensity, which complements the adhesion belongings among the rubber asphalt and steel slag aggregates.

(IV) Melkamu Birlie (2021) studied the Investigation and optimization of waste LDPE plastic as a modifier of asphalt mix for highway asphalt in case of Ethiopian roads. This observation aimed toward investigating the impact of the usage of waste LDPE plastic as a modifier of virgin bitumen. This observe additionally tries to increase the benefit of using moist blending technique over dry. Four modified bitumen mixes organized with 4, 6, 8 and 10% waste LDPE plastic content by way of the weight of most beneficial bitumen content material (OBC) at exclusive mixing temperatures (160, 170, and 180◦C) and one of a kind blending times (1, 1.5 and 2 hours) to evaluate penetration value, softening point and ductility. 170◦C mixing temperature and 1.5 hour blending time results, homogeneous mix among bitumen and waste LDPE plastic materials compared to different mixing temperatures and mixing instances. Softening point value has a direct have an effect on on the resistance to everlasting deformation of the asphalt aggregate. The addition of LDPE Plastics into virgin bitumen will increase especially the softening factor of the changed bitumen. This phenomenon shows the resistance of LDPE modified bitumen to warmth is extended and it reduces its tendency to soften in hot weather circumstance. Thus, the addition of waste LDPE plastic enhances the softening temperature of bitumen. It is able to be stated that the bulk density of compacted mix increases as the bitumen content material increases until it reaches the maximum peak at bitumen content material of 5.3%. As the end result, becomes not able to resist heavy loads and highly susceptible to temperature variations. The value of VMA and VA of waste LDPE changed asphalt blend barely will increase with respect to that of non-modified asphalt blend. But the VFB of waste LDPE modified asphalt mix well-known shows a totally mild lower while it's miles in comparison to traditional asphalt mix.

(V) Shahreena Melati Rhasbudin (2018) Shah investigated the Strength Properties of Polyethylene in Bituminous Mixtures for Flexible Pavement. The purpose of this study is to evaluate the characteristics of PE changed bituminous combination in assessment to conventional bituminous combination. Low Density Polyethylene (LDPE) and High Density Polyethylene (HDPE) have been blend together as a modifier, delivered to the combination developing a thin coating on the combination surface. From the findings, it may be concluded that the Marshall balance increased extensively with the addition of PE. This indicates that the PE increases the power of the mix and enhance load wearing functionality. By coating the mixture with PE, improves the strength and reduce water absorption. In long term, this could help to reduce stripping problem. Marshall blend layout houses for control and changed mix conform to Standard Specification for Road Works. As use of HDPE-LDPE blend helps to lessen amount of bitumen, this will reduce the fee of pavement substances subsequently. The addition of HDPE-LDPE blend into bituminous mixture improves the satisfactory of compacted carrying path.

(VI) Anjana Patel (2020) Development of Improved Dense Graded Bituminous Macadam with Low Density polyethylene and High Density Polyethylene with Zykotherm Intermixing. Modified DBM mixes, the Marshall Stability Test, Penetration Test, and Softening Point Test had been performed to check the effectiveness of the polyethyelene in mix design of dense bituminous macadam. According to the findings, zycotherm boosts the adhesive residences of the combination in a herbal way. As the amount of HDPE polymer inside the specimen will increase, the ductility of specimen improves because it has a excessive tensile electricity. This technology is surprisingly essential in phrases of expenditure discount in construction for the reason that it's far very beneficial in fee lowering of bitumen in a aggregate.

3. 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.

(a) (b)

Figure 1. (a) Processed LDPE Plastic & (b) BOF steel slag 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 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 then 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.

4. 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.

(I) 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.

(II) 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.

(III) 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.

(IV) 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.

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

(V) 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 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.

5. RESULT AND DISCUSSION

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 VG 30 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.

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 (Gm) (gm/cc)	2.371	2.378	2.377
Average density (Gm)	2.376		
Theoretical specific gravity (Gt)	2.497		

Void in mineral aggregate VMA(%)	16.781		
Air void (Vv)(%)	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		

Calculations and formulae.

Bulk specific gravity of mix (Gm):

$$Gm = Wm/Ws-Ww \tag{1}$$

Where Ww is the weight of the mould in water, Ws being weight in air in saturated surface dry and Wm is the weight in air.

B. Theoretical density (Gt):

$$Gt= (W1+W2+W3+Wb)/(W1/G1+W2/G2+W3/G3+Wb/Gb) \tag{2}$$

Where W1 and G1 being weight and apparent specific gravity of coarse aggregate in the total mix, W2 and G2 being weight and apparent specific gravity of fine aggregate in the mix, W3 and G3 are the weight and apparent specific gravity of the filler material and Wb and Gb are the weight and apparent specific gravity of the binder or bitumen.

C. Air void percent (Vv):

$$Vv = (Gt-Gm)100/Gt \tag{3}$$

D. Percentage volume of bitumen (Vb):

$$Vb =Gm.Wb/Gb \tag{4}$$

E. Voids in mineral aggregate (VMA):

$$VMA =Vv+Vb \tag{5}$$

F. Voids filled with bitumen (VFB):

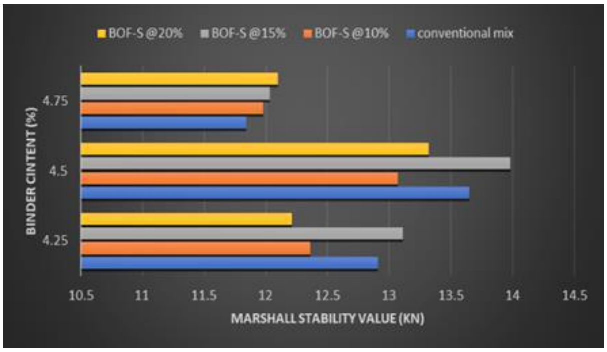
$$VFB = Vb.100/VMA \tag{6}$$

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

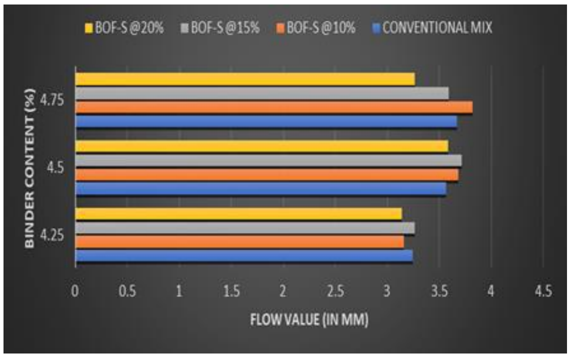
Steel slag content (%)	15%		
Binder content (%)	4.25%	4.50%	4.75%
Weight in air(gm)	1261.2	1276.7	1286.3
Weight in water (gm)	743.2	769.3	780.2
Weight in air SSD (gm)	1275	1283.2	1292.6
Volume (cc)	531.8	513.9	512.4
Density (Gm) (gm/cc)	2.371	2.489	2.540
Theoretical specific gravity (Gt)	2.491	2.599	2.686
Void in mineral aggregate VMA (%)	16.897	17.650	20.745

Air void (Vv) (%)	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.



(a)



(b)

Figure 2. (a) Comparison graph between modified and unmodified for Marshall Stability value & (b) Comparison graph between modified and unmodified for Flow value.

6. 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.

(I) 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. 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.

(II) The average flow value corresponding to the maximum stability value of the modified mix (MAM) (BOF steel slag @15%) increased very narrowly about 3.65% when compared to conventional mix. Then, the value of stability value has abruptly decreased at 20% by steel slag which concluded to be uneconomical for further addition of it

(III) 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. Hence, signifies that the resistance to distortion, shearing stresses, rutting and displacement of the modified asphaltic mould mixes may have been improved. Thus there is a slight enhancement of the mechanical characteristics of the mix.

7. 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

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