A STUDY ON THE EFFECT OF RECYCLED AGGREGATE, WASTE PLASTIC & SISAL FIBER ON THE PROPERTIES OF BITUMINOUS CONCRETE

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Abstract - *A Huge quantity of raw material consumption in the construction industry becomes one of the main factors that cause depletion of natural and mineral resources. The disposal of plastic waste is a serious threat and also challenging to the environment resulting in global warming and pollution. The use of plastic waste in the bituminous concrete is not only a solution for the above-discussed problem but also improves bituminous mix characteristics and strength. Researchers have observed that the common defects in pavement such as corrugation, potholes, ruts; etc get reduced when the bituminous concrete is prepared by mixing waste plastic. In the present study shredded waste plastic in varying percentages (2, 4, 6, 8, 10 & 12%) by weight of bitumen were added in hot bitumen and recycled aggregates were added in varying percentages (10, 20, 30, 40 & 50%) as replacement of natural coarse aggregates. Various tests on aggregate (Natural & Recycled) and bitumen were conducted for finding physical properties. Marshall Test was also conducted on the bituminous concrete prepared with varying percentages of waste plastic and recycled aggregates as mentioned above to find out the most suitable proportion of bituminous concrete. Sisal fibre was also added at the rate of 0.3% by the weight of the mix to further enhance its property. From the test results, the bituminous concrete (M5- prepared with 40% recycled aggregate, 60% natural aggregate, 8% waste plastic & 0.3% sisal fibre) for bitumen content 5% was found to be most suitable for bituminous concrete pavement.*

Key Words: RAP, Recycled Aggregate, Waste Plastic, Sisal Fibre, Marshall Stability, Bituminous Concrete

1. INTRODUCTION

At present many infrastructure development projects are undertaken in India and therefore demand for natural resources such as coarse aggregate, sand, etc are increasing day by day. In addition to this production of coarse aggregate is also getting reduced due to the restriction imposed on aggregate crushers to minimise air pollution. A huge quantity of raw material consumption in the construction industry becomes one of the main factors that cause environmental damage and pollution to our motherland and the depletion of natural and mineral resources. As per the report of Central Pollution Control Board (CPCB) Delhi, in India, 48million tons of solid waste is produced out of which 14.5 million tonnes waste is produced from the construction waste sector, out of which only 3% waste is used for the embankment. Out of the total construction demolition waste, 40% is of concrete, 30% ceramics, 5% plastics, 10% wood, 5% metal, & 10% other mixtures. As reported by global insight, growth in the global construction sector predicts an increase in construction spending of 4800 billion US dollars in 2013. These figures indicate tremendous growth. Hence it became necessary to use recycled aggregates in place of natural aggregates to meet out the market demand. Every year a huge quantity of waste plastic is being generated in India as well as all over the world. The disposal of waste plastic imposes major threats to the environment. The use of waste plastic in road construction is one of the solutions for the mitigation of its disposal issue. Many research works have already been carried out by researchers in this area. Sulochana T (2016) did an experimental investigation to increase the strength of bitumen by using plastic waste. G. Ramesh Kumar (2017) studied on partial replacement of bitumen with waste plastic and polypropylene in road construction. Sisal fibre has become a focus of research for scientists and researchers. It is naturally and locally available fibre in India which has been economically beneficial as well as shows its good characteristic. Sisal fibre is obtained from leaf skin after removing the pulp. Sisal fibre neither attracts dust particles nor absorbs water and moisture. The use of sisal fibre gives better strength, durability and prevents it from drain down the mix.

1.1 The objective of the Study:

In this paper, an attempt has been made to find out the effect of recycled aggregate, waste plastic & sisal fibre on the properties of bituminous concrete. The objective of the present study is mentioned below:

- To study the effect of recycled aggregate, waste plastic and sisal fibre on the properties of bituminous concrete.
- To determine the optimum percentage of waste plastic and recycled aggregate to get the most suitable bituminous concrete.

1.2 Scope of the Study:

Based on the objective, the scope of the study is framed out as discussed below:

- Collection of natural coarse aggregate, ordinary bitumen, sisal fibre from a local dealer, waste plastic from municipal waste recycling plant and bituminous concrete from the reclaimed pavement.
- Shredding of waste plastic.
- Extraction of bitumen from the reclaimed aggregates to get the recycled aggregate.
- To find out the physical properties of natural and recycled coarse aggregates.
- To find out the properties of bituminous concrete prepared with mixing recycled aggregate, waste plastic and sisal fibre in varying percentages.
- Comparison of the results and recommendation of the most suitable mix for using the bituminous concrete pavement.

2. Literature Review:

Rashid J et al (2019) analyzed the effect of the use of Reclaimed asphalt pavement (RAP) in bituminous concrete. They used different parentages of RAP (25, 30, 35, & 40%) to find optimum percentages of RAP for bituminous concrete and conducted various tests such as penetration, ductility, Marshall Stability for finding engineering characteristics of RAP. They concluded that mix with 35% RAP has a similar result as virgin bituminous concrete and by using it cost of the project was reduced by 50%.

G. Ramesh Kumar et al (2017) did an experimental study on partial replacement of bitumen with waste plastic and polypropylene in road construction. They have used waste plastic and polypropylene in varying percentages of 1, 3, 5, & 7% of the weight of bitumen. They found that water resistivity, capacity and Stability of the mixes were increased. They found a decrease in penetration, ductility value and increase in softening point, flash & fire point and Stability value of the mix.

Amit kundal & Dr Amit Goel (2019) studied bituminous mixes with sisal fibre. They have added sisal fibre in the bituminous mix in varying percentages (0-0.8%) and found 0.4% as optimum fibre content. Various tests such as Marshall Stability and drain down were conducted. They found that with the addition of sisal fibre in bituminous mixes Marshall Stability value and durability increase, whereas Flow value and percentage air void decreases.

3. Methodology Adopted:

In the present study, detailed literature was reviewed related to the topic and some of them are presented above. Experimental investigations were carried out in the present study presented here. Different materials used for this project work, including details of tests conducted in the laboratory are also discussed.

3.1 Material used:

3.1.1 Natural Coarse Aggregates:

An aggregate that has great and adequate quality, hardness, and strength must be picked. This is primarily responsible to resist abrasion action or stress occurring on roads. Coarse aggregates for this experimental work were collected from the ongoing construction site at the NITTTR Bhopal campus.

3.1.2 Recycled Coarse Aggregate:

Recycled aggregate from reclaimed asphalt pavement (RAP) was used as a replacement for natural coarse aggregates. Coarse aggregates were recycled to find their physical properties to check whether it is suitable as surface coarse aggregates or not. RAP for this experimental work was collected from Biaora- Rajgarh (MP). The collected RAP sample is shown in photograph figure 1.

The bitumen was extracted from aggregates obtained from a reclaimed asphalt pavement in Material Testing Lab at NITTTR, Bhopal. For this purpose, the reclaimed aggregates were heated at 60°C for 30 minutes and aggregate lumps were broken down. The broken lumps of reclaimed aggregates were put in the bowl of the bitumen extraction machine and benzene was added to it. The mix was rotated at 180 RPM for one minute in a bitumen extractor machine. The process was repeated one more time and aggregates were taken out from the bowl. These aggregates were used as recycled aggregate in the preparation of a bituminous sample. The same gradation of natural coarse aggregate was used for the recycled coarse aggregate. The process is also shown in figures 1 to 3.



Figure 1: Collected RAP sample **Figure 2: Addition of benzene** **Figure 3: Recycled aggregate**

3.1.3 Waste plastic:

Poly-ethylene, polystyrene, polypropylene are the types of plastic that are obtained from different sources like plastic carry bags, milk pouches, wrappers are used in this work. Shredded waste plastic is mixed with hot bitumen which improves bituminous properties. The use of waste plastic in this research is passing through a 4.75 mm IS sieve retained on a 2.36 mm sieve. Specific gravity and melting point are found to be 1.05 and 160-210 C˚ respectively. Locally available waste plastic is used shown in figure 4.

Figure 4: Shredded waste plastic

3.1.4 Sisal fibre:

The sisal fibre is mainly used in paper, cloths, footwear, bags, rope, geotextiles, etc. It is also used as fibre reinforcement for composite fibreglass, cement and rubber products. In this project work, sisal fibre is used to enhance the property of the bituminous mix. The diameter and length of the sisal fibre used in this thesis work are 0.25mm and 50mm respectively. The specific gravity of sisal fibre is found to be 0.71. A sample sisal plant and fibre are shown in figure 5.

Figure 5: Sisal plant and fibre

3.1.5 Ordinary bitumen:

Bitumen is a material that is a byproduct of the petroleum refining process. It is highly viscous at a temperature above 100 degrees Celsius and is solid at room temperature. In this study, 80/100-grade bitumen is used. Various tests such as Penetration, ductility, softening point, specific gravity, flash & fire point were conducted.

3.1.6 Modified Bitumen:

The ordinary bitumen was modified using waste plastic. For this purpose, the weight of the ordinary bitumen was considered as 500 gm and waste plastic was added in varying percentages of the weight of bitumen. The details of mix proportion for modifying bitumen are given in Table 1 and the process is shown in figure 6.

Table 1: Mix proportion of Modified Bitumen

Mix Abbreviation	Percentage of Waste Plastic by weight of bitumen
MB1	2
MB2	4
MB3	6
MB4	8
MB5	10
MB6	12

Here, Mix abbreviation ‘MB’ stands for modified bitumen.

Figure 6: Heating of Bitumen and Mixing of Waste plastic

3.2 Numerical Study

Various tests conducted on natural as well as recycled coarse aggregate are described below-

3.2.1 Tests on coarse aggregate

Following tests were conducted on natural as well as recycled coarse aggregates to find out the physical properties of aggregates.

- Sieve analysis
- Specific gravity & Water absorption
- Aggregate Impact Value Test
- Los Angeles Abrasion Test
- Aggregate Crushing Value Test

3.2.1.1 Sieve Analysis:

The sieve analysis of the coarse aggregate is carried out in the Construction Material Testing lab at NITTTR, Bhopal. The test was conducted by taking 3000 gm of coarse aggregate sample and the result is given in Table 2 and also shown in figure 7.

Table 2: Sieve Analysis of Natural Coarse Aggregate

S. No	IS-Sieve (mm)	Weight Retained (gm)	Percentage Retained	Percentage Passing	Cumulative Percentage weight Retained
1.	40	0.00	0.00	100.00	0.00
2.	20	72.6	2.42	97.58	2.42
3.	10	2432.4	81.08	16.50	83.50
4.	4.75	436.2	14.54	1.95	98.05
5.	Pan	58.50	1.95	0	100

Figure 7: Sieving of aggregates

As it can be seen from the above Table, The grading of coarse aggregate as per IS code 383:1970 falls under Single Sized aggregate of nominal size 20 mm.

3.2.1.2 Specific Gravity:

The specific gravity of coarse aggregate can be defined as the ratio of the weight of coarse aggregate in the air to the weight of an equal volume of water displaced by saturated surface dry aggregate. The specific gravity of coarse aggregate test is performed in the Construction Material Testing lab at NITTTR, Bhopal.

3.2.1.3 Water Absorption:

Water absorption of aggregate gives an idea of strength. Aggregates with more water absorption are more porous and are not suitable for construction works unless they are found to be acceptable based on impact, strength and hardness tests. This test is conducted according to IS 2386-1963 in Construction Material Testing Lab at NITTTR, Bhopal.

3.2.1.4 Aggregate Impact Value Test:

An aggregate impact test is carried out to find out the toughness of stone aggregate under repeated impact load of the vehicle. This test is carried out according to IS: 2386 (IV)-1963 in Material Testing Lab at NITTTR, Bhopal. Test results are given in Table 4.

3.2.1.5 Los Angeles Abrasion Test:

Due to the movement of heavy traffic on the road, the aggregates are continuously subjected to bearing action on the surface layer of the road. Therefore, aggregate used in the roads surface course should be sufficiently strong to resist such traffic abrasion. To find out the abrasion value of the aggregate used in the present work, Los Angeles Abrasion test has been performed in the material testing lab at NITTTR, Bhopal. The test has been performed according to IS: 2386 (IV)-1963. Test results are given in Table 4.

3.2.1.6 Aggregate Crushing value:

Aggregates used in the construction of pavement should be strong enough to resist crushing from the wheel load of running vehicles. The strength of aggregate is determined by the crushing value test. Aggregate crushing value provides a relative measure of resistance to crushing under a gradually applied compressive load. Less is the crushing value more will be the strength of aggregate. Aggregate crushing value test has been performed in the material testing lab at NITTTR, Bhopal. The test has been performed according to IS: 2386 (IV)-1963. Test results are given in Table 4.

3.3 Marshall Stability Test:

Marshall Stability test was conducted to find out the effect of recycled aggregate, waste plastic and sisal fibre on the properties of the bituminous mix. Marshall Stability test is a standard laboratory method, used for determining the stability and flow value of bituminous mixes. Marshall Test was carried out according to ASTM D 1559. The Marshall stability of the mix is the load-carrying capacity of a mix at a standard test temperature of 60°C and is measure in KN. The flow value is the warp of specimen undergo during the period of loading.

3.3.1 Preparation of Marshall Test samples:

Marshall Test samples were prepared using different mix proportions as mentioned in Table 3. The gradation of coarse aggregates was considered as mentioned under S. No 3.2.1.1 – Sieve Analysis in Table 2. 80/100 grade of bitumen was used and the percentage of bitumen was considered as 4.5, 5, 5.5 & 6% for the preparation of the test samples.

Table 3: Mix proportion

Mix Abbreviation	Percentage of Waste Plastic	Percentage of Recycled Aggregate	Percentage of Sisal Fiber
M1	0%	0%	0%
M2	2%	10%	0.3%
M3	4%	20%	0.3%
M4	6%	30%	0.3%
M5	8%	40%	0.3%
M6	10%	50%	0.3%

The total weight of the mix prepared was 1200 grams. The test samples were prepared using the mould of size 101.6mm diameter and 63.5mm depth. The quantity of ingredients for each percentage of bitumen content and each type of mix was calculated. The test samples were prepared according to the ASTM D 1559. The prepared test samples are shown in figure 8.

Figure 8: Prepared Marshall Sample

4. Results & Discussions:

The details of laboratory investigations carried out for the present study is presented above under serial number 3.2. Results obtained from the laboratory investigations are presented and discussed below.

4.1 Physical Properties of natural and recycled aggregates:

Various tests are conducted to find out the physical properties of natural and recycled aggregates used in the present work in the Material Testing Lab at NITTTR, Bhopal and the results are given in Table 4.

Table 4: Physical Properties of Natural and Recycled coarse Aggregates

Physical Property	Test method	Tests result for natural aggregates	Tests result for recycled aggregate	Values as per MORTH Specification
Aggregate Impact Value (%)	IS: 2386 (P IV)	19.67	29.41	30% Max
Los Angeles Abrasion Value (%)	IS: 2386 (P IV)	15.51	25.73	30% Max
Aggregate Crushing Value (%)	IS: 2386 (P IV)	24.19	29.35	30% Max
Water Absorption (%)	IS: 2386 (P III)	0.405	2.25	2 % Max
Specific gravity	IS: 2386 (P III)	2.77	2.52	2.5-3

It can be seen from the above table that the impact value, Los Angles Abrasion value and Crushing value for both natural and recycled aggregates and water absorption value for natural aggregates are within the limit of MORTH specification requirement. So these can be used for road construction work. The water absorption value for recycled aggregate is marginally higher than the MORTH requirement.

4.2 Properties of the bituminous concrete mix:

Marshall Stability Test on the samples of bituminous concrete mix prepared with ordinary as well as modified bitumen. The test results are given in Tables 6 to 9 and graphs are shown in figures- 9 to 13. Requirements of the mix as per IRC: 37 are given in Table 5.

Table 5: Requirement of the mix as per IRC: 37

S. No	Mix Properties	Values as per IRC
1.	Marshall Stability (KN)	8.2
2.	Marshall Flow (mm)	2-4
3.	Percent air void in the mix (%)	3-5

4.	Percentage voids in mineral aggregate filled with bitumen (VFB) %	75-85
5.	Percentage voids in mineral aggregate (VMA) %	13-16

Table 6: Marshall Test Results for 4.5% bitumen content

Mix Abbreviation	Percentage air voids (Vv)	Voids in mineral aggregate (VMA)	Voids filled with bitumen (VFB)	Stability (KN)	Flow value (mm)
M1	6.93	17.29	59.51	13.51	3.22
M2	6.42	16.79	61.76	14.51	2.92
M3	5.53	15.92	65.26	14.67	2.83
M4	5.82	16.14	63.94	15.76	2.71
M5	4.77	15.11	68.43	16.22	2.58
M6	4.65	14.97	68.93	15.45	2.59

It can be seen from the above table that the value of percentage air voids (Vv), Voids in mineral aggregates (VMA) & Flow value is getting reduced, voids filled with bitumen (VFB) and Stability value are increasing with the increased percentage of waste plastic, sisal fibre & recycled aggregate. However mix M5 (8% waste plastic, 40% recycled aggregate & 0.3% sisal fibre) was found to be most suitable for bituminous concrete mix prepared with 4.5% bitumen content as it satisfies all the criteria of IRC: 37 guidelines except VFB criteria.

Table 7: Marshall Test Results for 5% bitumen content

Mix Abbreviation	Percentage air voids (Vv)	Voids in mineral aggregate (VMA)	Voids filled with bitumen (VFB)	Stability (KN)	Flow value (mm)
M1	5.06	16.70	69.70	14.44	3.39
M2	4.71	16.35	71.19	16.11	3.15
M3	4.35	15.94	72.71	16.14	2.96
M4	4.22	15.78	73.25	17.03	2.78
M5	3.57	15.11	76.37	17.67	2.68
M6	3.45	14.96	76.93	15.63	2.70

It can be seen from the above table that the value of percentage air voids (Vv), Voids in mineral aggregates (VMA) & Flow value is getting reduced, voids filled with bitumen (VFB) and Stability value are increasing with the increased percentage of waste plastic, sisal fibre & recycled aggregate. However mix M5 (8% waste plastic, 40% recycled aggregate & 0.3% sisal fibre) was found to be most suitable for bituminous concrete mix prepared with 5% bitumen content as it satisfies all the criteria of IRC: 37.

Table 8: Marshall Test Results for 5.5% bitumen content

Mix Abbreviation	Percentage air voids (Vv)	Voids in mineral aggregate (VMA)	Voids filled with bitumen (VFB)	Stability (KN)	Flow value (mm)
M1	3.90	16.76	76.73	13.93	3.56
M2	3.27	16.26	79.88	17.27	3.24
M3	3.45	16.22	78.72	18.53	3.10
M4	3.06	15.85	80.69	19.40	2.98
M5	2.36	15.11	84.38	20.50	2.83
M6	2.09	14.82	85.89	16.35	2.83

It can be seen from the above table that the value of percentage air voids (Vv), Voids in mineral aggregates (VMA) & Flow value is getting reduced, voids filled with bitumen (VFB) and Stability value is increasing with the increased percentage of waste plastic, sisal fibre & recycled aggregate. However, for mix M5 (8% waste plastic, 40% recycled aggregate & 0.3% sisal fibre) stability value is maximum but percentage air voids are not as per IRC: 37 guidelines. So mix M4 (6% waste plastic, 30% recycled aggregate & 0.3% sisal fibre) was found to be most suitable for bituminous concrete mix prepared with 5.5% bitumen content as it satisfies all the criteria of IRC: 37 guidelines.

Table 9: Marshall Test Results for 6% bitumen content

Mix Abbreviation	Percentage air voids (Vv)	Voids in mineral aggregate (VMA)	Voids filled with bitumen (VFB)	Stability (KN)	Flow value (mm)
M1	3.68	18.30	75.62	12.89	3.57
M2	3.29	17.83	77.73	15.23	3.34
M3	3.31	17.39	79.35	15.58	3.13
M4	3.05	16.87	81.92	16.63	3.06
M5	2.52	16.30	84.53	16.97	2.85
M6	1.68	15.88	86.77	15.44	2.93

It can be seen from the above table that the value of percentage air voids (Vv), Voids in mineral aggregates (VMA) & Flow value is getting reduced, voids filled with bitumen (VFB) and Stability value are increasing with the increased percentage of waste plastic, sisal fibre & recycled aggregate. However, for mix M5 (8% waste plastic, 40% recycled aggregate & 0.3% sisal fibre) stability value is maximum but percentage air voids are not as per IRC: 37 guidelines. So mix M4 (6% waste plastic, 30% recycled aggregate & 0.3% sisal fibre) found to be most suitable for bituminous concrete mix prepared with 6% bitumen content as it satisfies all the criteria of IRC: 37 guidelines.

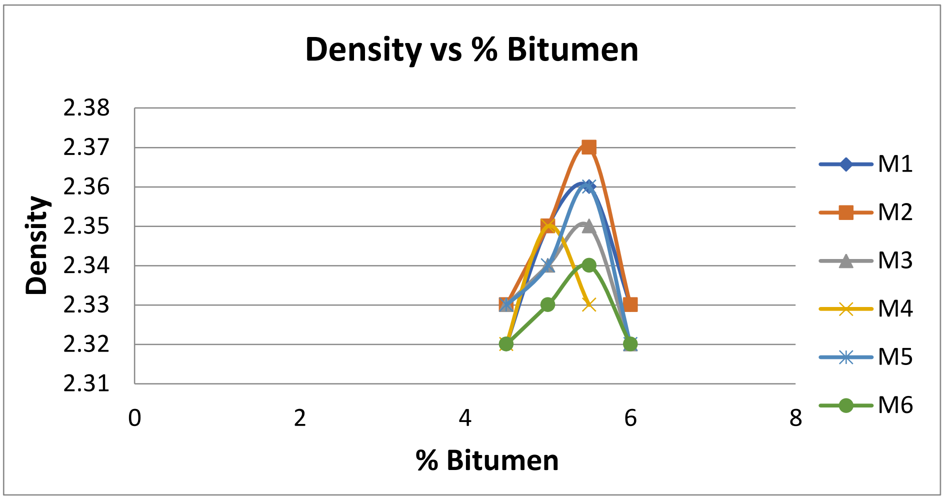

Figure 9: Density vs. % Bitumen Graph

It can be seen from the above graph, the density of bituminous concrete is first increasing with the increased percentage of bitumen up to optimum bitumen content. At more than optimum bitumen content, it started decreasing. Maximum density is for mix M2.

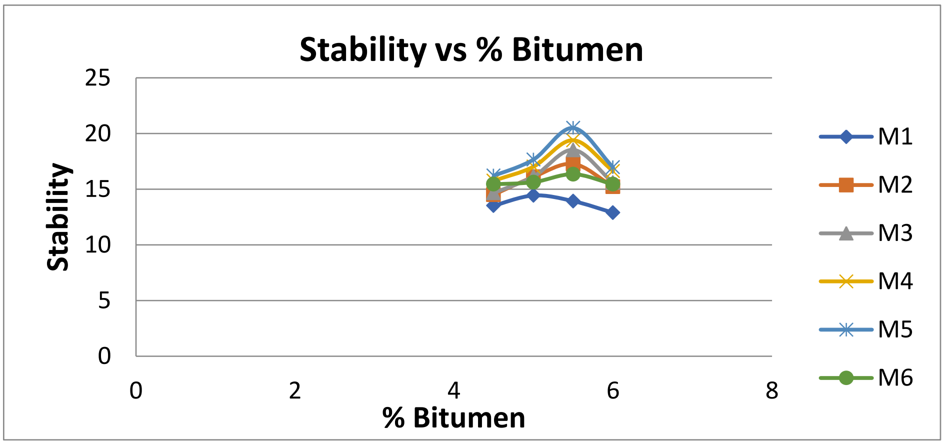

Figure 10: Stability vs. % Bitumen Graph

It can be seen from the above graph, stability of bituminous concrete is first increasing with the increased percentage of bitumen up to optimum bitumen content. At more than optimum bitumen content, it started decreasing. The maximum stability value is for mix M5.

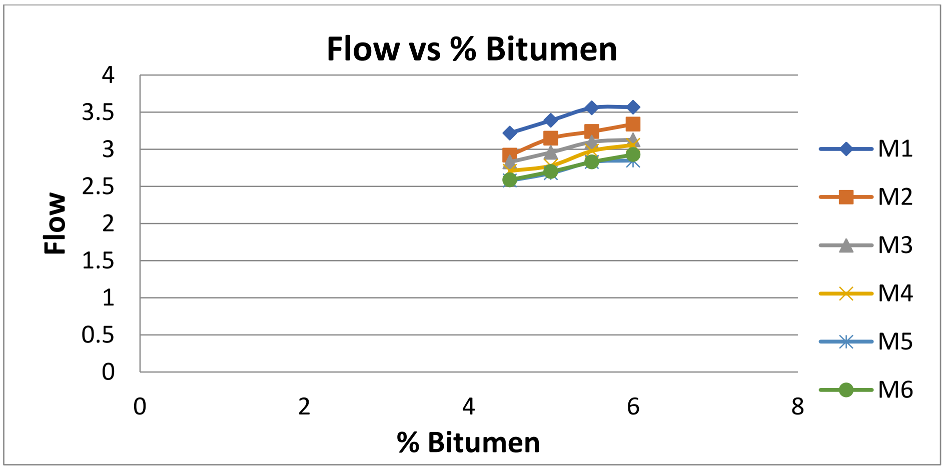

Figure 11: Flow vs. % Bitumen Graph

It can be seen from the above graph, flow value is increasing with the increased percentage of bitumen content.

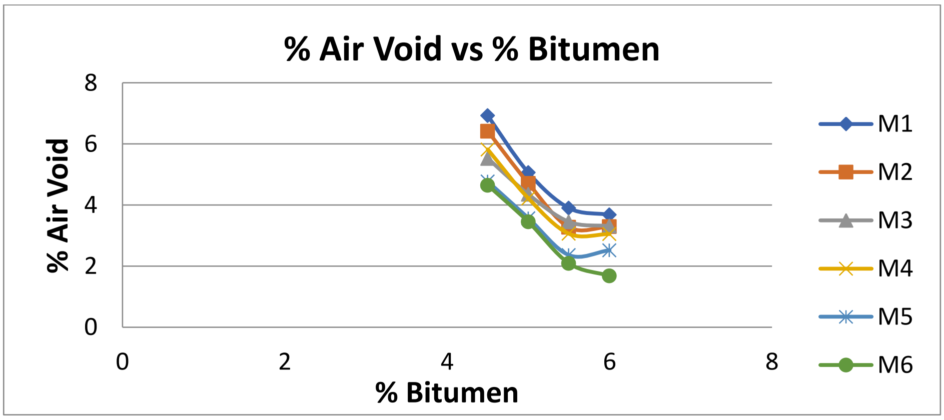

Figure 12: Percentage air void vs. % Bitumen Graph

It can be seen from the above graph, percentage of air void is decreasing with an increased percentage of bitumen. Minimum air void is for mix M6.

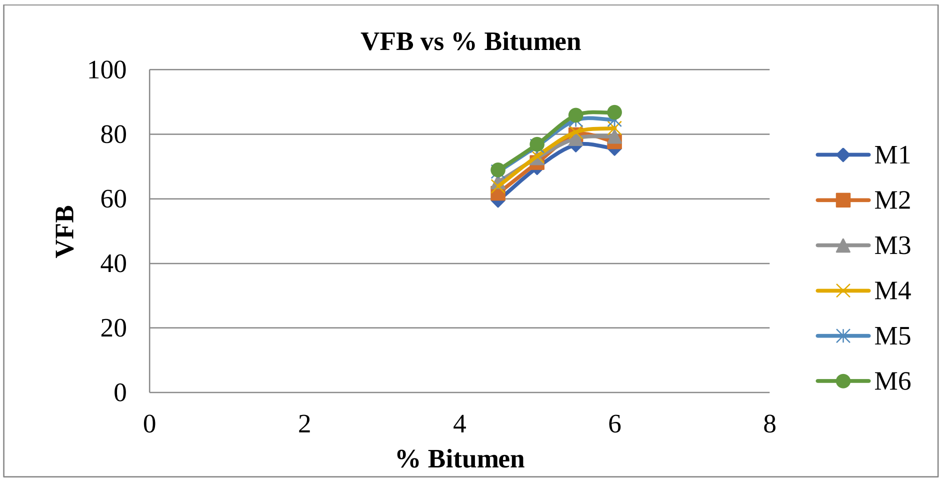

Figure 13: VFB vs. % Bitumen Graph

5. Conclusions:

From the test results obtained from the experimental investigations, the following conclusions can be drawn:

5.1 Conclusion on the properties of recycled aggregate:

Physical properties of the recycled aggregates were found as per MoRTH specification hence it can be used in the bituminous concrete.

5.2 Conclusion on the properties of bituminous concrete:

Marshall Stability-

Marshall Stability value is increasing with the addition of waste plastic, sisal fibre and recycled aggregate from mix M2 to M5 (8% waste plastic, 0.3% sisal fibre & 40% recycled aggregate) then after it started decreasing. Maximum Marshall Stability value for all bitumen content is in the case of mix M5 and its maximum value is 20.50 KN at 5.5% bitumen content. The minimum value is 12.89 KN at 6% bitumen content in the case of mix M1. Marshall Stability is resistance to distortion, displacement, rutting and shearing stress. Hence the mix prepared with modified bitumen and recycled aggregates can be used for heavy traffic load. Minimum Marshall Stability value as per IRC: 37 should be 8.2 KN.

Flow value-

Flow value is decreasing with the addition of waste plastic, sisal fibre and recycled aggregates. Its maximum value is 3.57 at 6% bitumen content in the case of mix M6. The minimum value is 2.58 at 4.5% bitumen content in the case of mix M5. In both cases values falls within the limits given by IRC: 37 (2-4 mm). A higher flow value is undesirable as it causes rutting in the pavement. Modified bitumen can be used to reduce flow value.

Percentage air voids-

Percentage air voids (Vv) is decreasing with the addition of waste plastic, sisal fibre, recycled aggregates and the maximum value obtained as 6.93 at 4.5% bitumen content in case of mix M1 (Normal mix). Minimum value is 1.68 at 6% bitumen content in case of mix M6 (10% waste plastic, 50% recycled aggregate & 0.3% sisal fiber). Higher air voids content causes rutting in the pavement on the movement of traffic load. A minimum amount of air voids is required to avoid instability during compaction and to provide space for bitumen flow in long term consolidation under traffic loads.

From the above discussions, the bituminous concrete (M5- prepared with 40% recycled aggregate, 60% natural aggregate, 8% waste plastic & 0.3% sisal fibre) for bitumen content 5% found to be most suitable for bituminous concrete pavement as it fulfils all the criteria such as Marshall Stability, Flow value and Percentage air voids as per IRC: 37 guidelines.

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