Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 05, May-2016

Study of Behaviour of Bitumen Modified with Crumb Rubber

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***Abstract*- The aim of the study was to utilize the waste materials i.e. crumb rubber waste for mass scale utilization such as in highway construction in an environmental safe manner.**

As a first part of this study, an attempt was made to assess the stabilization of the bitumen containing crumb rubber waste in shredded form by performing basic tests such as Penetration Test, Ductility Test, Softening Point Test, Viscosity Test and Flash & Fire Point Tests. On the basis of the performance of the modified bitumen, the range of optimum percentages of crumb rubber waste were selected for further investigations related to Bituminous Concrete Mixes such as Semi Dense Bituminous Concrete (SDBC). Marshall Values, namely Marshall Stability Value, Marshall Flow Value, Voids present in air, Voids in Aggregates and Voids in Bitumen, determined from Marshall Stability Test, serve as the benchmark values to assess the quality of Bituminous Concrete.

The design and performance of Bituminous Concrete mainly depends upon the quality and percentage of binder used. Experimental investigations were undertaken to check the pavement worthiness of these mixes

Keywords – Crumb rubber, ductility of bitumen.

I. INTRODUCTION

In the present scenario disposal of rubber wastes produced from different Industries is a great problem. These materials lead to environmental pollution in the atmosphere nearby locality due non biodegradable property. Most of the construction materials used for roads are soil, stone aggregate, sand, bitumen, cement etc. The availability of natural materials is declining. Also, cost of extracting good quality of natural material is increasing. To overcome this problem, it is recommended to use alternative materials for highway construction, by which the pollution and disposal problems may be reduced. The need for these solid wastes in India, it was in need to test these materials and to develop specifications for usage of waste tyres in road construction in which it may leads to higher economic returns. The possibility of using these materials should be developed for low volume roads construction in various parts of our country. The necessary specifications should be formulated to maximize the use of solid wastes in different layers of the road pavement.

Pavement performance studies are to be done after post construction stage for construction of roads using rubber waste with two major advantages:

(i) It will help in clearing the land of huge dumps of wastes.

(ii) It will also help to preserve the natural sources of aggregates, and protecting the environment. Rubber tyres are user friendly but not eco friendly since they are non-biodegradable. The process of disposing waste tyres in landfills and burning in open space is becoming nuisance because of rapid depletion of available landfill sites and clear environment respectively.

The conventional bituminous mix consists of aggregate and 3 to 5 percent bitumen by weight of the aggregate. The tyre rubber scrap can be incorporated into bitumen, which is known as modified bitumen and granulated or ground rubber or crumb rubber are used as a portion of the fine stone aggregate. The use of waste in hot bituminous mixes enhances the performance of pavement, protect environment and provide economic and quicker roads.

A. General

Definition of Rubber crumb: Crumb rubber is recycled rubber produced from automobiles and truck scraped tires. During the recycling process of these rubber crumb, steel and tire cord (fluff) are removed, and tire rubber are produced with a granular consistency.

1)Binder modification:

Binder properties may be improved by different process and materials. Binder modification has been driven by the increase in traffic loads, new refining technologies, enhancement in polymer technology, the increasing need to recycle waste material such as plastic bag, plastic bottle, rubber and etc.

2)Purpose of Bitumen modification:

- To obtain softer blends at low temperature for reducing cracks.
- To increase the stability and strength of mixtures.
- To improve the asphalt cohesive strength in Pavements
- To improve oxidation and resist aging
- To reduce costs of pavement

B. Use of crumb rubber in civil engineering:

In India waste tyres are termed as solid waste or hazardous waste. It is found that about 60% of (retreaded) waste tyres are disposed in the urban and also in rural areas. The hazards of waste tyres are air pollution produced due to open burning of tyres (particulates, odour, visual impacts, and other harmful contaminants such as polycyclic hydrocarbon, furans and oxides of nitrogen), aesthetic pollution which are caused by

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 05, May-2016

stockpiles of waste tyre and other defects such as changes in hydrological regimes when gullies and watercourses become dumping sites.

C. Sources of Generation of Crumb rubber:

Crumb rubber is manufactured from two primary feedstocks: tire buffing (shredded rubber), a byproduct of tire retreading and scrap tire rubber.

On average, 10 to 12 pounds of crumb rubber can be derived from one passenger tire.

D. Advantages of Using Crumb Rubber Modified Bitumen:

- Higher resistance to deformation under increased road temperature improves smoothness to drive.
- Improved adhesion property and bonding nature with aggregates, Higher softening point, High flow resistance and Higher resistance to impact, withstanding heavy traffic.
- High skid resistance, Better road grip and smoothness in pavement during vehicle break application, which reduces road accident.
- Higher elongation and tensile strength, increases Elasticity. Reduction in thermal sensitivity, which avoids cracks caused under stress.
- Reduced degree of rutting, improves driving comforts even on higher axle loads
- High resistance to moisture or water absorption hence there is no damage to roads during rain and improper drainage.

E. Objective of Study

- The present study envisages the use of waste material i.e. waste tyres mixed with bitumen, which has potential use in highway and construction industry
- The large scale use of such materials will not only help in conserving the ecological balances, but will open up opportunities for the industries to produce a low cost material based on these waste, for mass scale applications.
- The study also encourages the use of these potentially hazardous wastes for mass scale without affecting the environment, cultivation, human and animal lives.

F. Materials

TEST MATERIALS

In this study, the materials used are:

(i) Bitumen
(ii) Crumb Rubber
(iii) Aggregates

II. LABORATORY INVESTIGATIONS

A. Aggregates (Coarse & Fine)

Aggregate forms the major part of the pavement structure. Aggregates are primarily used for bearing load stresses which are occurring on the roads and runways and have to resist water due to abrasive action of traffic. Aggregates are used in construction of cement concrete pavement, bituminous concrete pavement and also as granular base course underlying the superior pavement layers.

Fig 1 Crumb rubber

TABLE I

Test on aggregate	Coarse Aggregate
Specific gravity	2.71
Water absorption	0.38%
Aggregate Impact Value	22%
Aggregate Crushing Value	24.8%
Los–Angeles Abrasion Value	33%

B. preliminary tests

The present study on the behavior of thermal and binding property promoted that a study on the preparation of CR waste modified bitumen and its properties to find the suitability of the binder for road construction. Bitumen and crumb rubber is being mixed thoroughly, Before mixing the Crumb Rubber waste with bitumen in pans, bitumen would have to be heated up to about 160° C first. To achieve this, pans of bitumen were heated for 10-15 minutes. After that, Crumb Rubber in percentage of 4%, 6%, 8%, 10% and 12% was added into the pans and were mixed manually for about 2 minutes.

C. Sample Preparation

The sample preparation was done as per the following procedure.

a) Required quantities of coarse aggregate, fine aggregate & mineral fillers were taken in an iron pan.
b) The aggregates and filler are mixed together and heated to a temperature of 175^0 C to 190^0 C. This is because the aggregate and bitumen are mixed in molten state so preheating is required.
c) The bitumen was also heated up to its melting point prior to the mixing.
d) The required amount of shredded CR waste (say, 5 % by weight of bitumen) was weighed and kept in a separate container.
e) The aggregates in the pan were heated on a controlled gas stove for a few minutes maintaining the above mentioned temperature.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 05, May-2016

f) The CR (crumb rubber) waste is being added to the aggregate and was mixed for 2 minutes.
g) Now, the required quantity of first trial percentage of bitumen (say, 5 % by weight of mineral aggregates) is added to the heated aggregates and the whole mix was stirred uniformly and homogenously. This was continued for 15-20 minutes till they were properly mixed which was clearly seen from the uniform colour throughout the mix.
h) The mixing temperature for 80/100 grade bitumen may be around 154^0 C
i) Then the mix was transferred to a casting mould so as to obtain a compacted bituminous mix specimen of thickness 63.5 ± 3 mm.
j) This mix was then compacted by the Marshall Hammer.
k) 75 No. of blows were given on each side of the sample so that total of 150 No. of blows was given per sample.
l) Then these samples with moulds were kept separately and marked.
m) Vary the bitumen content in the next trial by +0.5% and repeat the above procedure.

Standard bitumen test

In order to characterize mechanical properties of Crumb Rubber some standard laboratory tests were conducted. All these tests replicate the actual field conditions in different ways. Different types of standard tests conducted on it are briefly described below:

TABLE 2

Sample	PenetrationValue ($1/10^{th}$ of mm)	Ductility Value (cm)
Bitumen	75	76
PB + 4% CR	48	20
PB + 6% CR	55	18.6
PB + 8% CR	68	18
PB + 10% CR	85	17.5
PB + 12% CR	105	17.1

TABLE 3

Sample	Softening Point (^{0}C)	Viscosity (seconds) At 60^0 C
Bitumen (PB)	45	196
PB + 4% CR	48	230
PB + 6% CR	50.5	320
PB + 8% CR	53	410
PB + 10% CR	55.5	450
PB + 12% CR	56	530

C. Marshal stability test

The samples to be tested are then kept immersed under water in a thermostatically controlled water bath maintained at 60 ± 1^0 C for 30 to 40 minutes. Marshall mix design is the standard design procedure for determining the mix ratio for bituminous road pavements for a particular bituminous concrete. The test procedure is used in designing and evaluating bituminous paving mixes. The test procedure is extensively used in routine tests program for the paving jobs. There are two major features of the Marshall method of designing mixes namely, (i) density-voids analysis and (ii) Stability Flow tests. The Marshall stability of the mix is probably defined as a higher load carried by a compacted specimen at a standard temperature of 60 ^{0}C. The flow value is the deformation of Test specimen undergoes during the loading up to the maximum load, in 0.25 mm units. In this test it is necessary to obtain optimum binder content for the type of aggregate mix and traffic intensity. Therefore the following steps for the design of bituminous mix which are adopted are given below.

a) Select grading type which is to be used in the test.
b) Choose the aggregates to be employed in the mix.
c) Determine the proportion of each aggregate used are required to produce the design grading.
d) Determine the specific gravity of the aggregate combination and of the asphalt cement.
e) Make up trial specimens with varying asphalt contents.
f) Determine specific gravity of each compacted specimen.
g) Make stability test on the specimens.
h) Calculate the percentage of Air voids, Voids in Mineral Aggregates (VMA) and the Voids which are Filled with Bitumen (VFB) in each specimen.
i) Calculate the optimum bitumen content from the data obtained.
j) Check the values of Marshall Stability, Flow value, Voids in mix and maximum Voids which are filled with bitumen obtained at the optimum bitumen content, with the design requirements. The design may be repeated if necessary when altering of the gradation is done so as to fulfill the design requirements.

Fig 2 Marshall stability Samples

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 05, May-2016

Fig 3 Closer View of Marshall Sample

Fig 4 Marshall Samples in Thermostatically Controlled Water Bath

Fig 5 Marshall stability test

D. Semi Dense Bituminous Concrete (SDBC)

General

Semi Dense Bituminous Concrete shall be used as a wearing course and shall not be laid directly over Water Bound Macadam (WBM) or any granular base. The item shall consists of mineral aggregates and appropriate binder mixed inside a hot mix plant and spread with a paver on a previously prepared base in accordance with the specifications and conforming to the lines, grades and cross sections.

Materials

Bitumen: The bitumen shall be of paving bitumen of Penetration Grade complying with Indian Standard Specifications for "Paving Bitumen" code of IS: 73, and of the penetration for Semi Dense bituminous concrete.

Coarse Aggregates: The coarse aggregates shall be taken from crushed rock, crushed gravel or any other hard material retained on the sieve size of 2.36 mm. The aggregate should be free from dust, hard and durable, of cubical shape and free from organic or other deleterious substances.

Fine Aggregates: Fine aggregates shall consist of naturally occurring mineral material or a combination of the two, passing the sieve size of 2.36 mm and then retained on the 75 micron sieve.

Fillers: Filler shall consist of finely divided mineral matter such as rock dust, hydrated lime or cement approved by the Engineer. The filler shall be graded within the limits.

III. TEST RESULTS AND DISCUSSION

The studies of properties of the crumb rubber waste blended bitumen show that the addition of crumb rubber waste to bitumen increases softening point, increases penetration value and decrease ductility. Moreover, it also increases Marshall Stability range value.From these observations the Optimum Bitumen Content for SDBC is 6%.

TABLE 4
Results of SDBC Mix using 80/100 Grade Bitumen

Bitumen Content	Marshall Stability Value	Flow Value	Bulk Density of the Mix	Air Voids	VMA	VFB
	S	F	G_m	V_V		
%	Kg	mm	gm/cc	%	%	%
5.0	736.64	3.26	2.412	3.787	15.03	74.81
5.5	843.65	3.77	2.402	3.499	15.76	77.80
6.0	963.00	4.13	2.395	3.116	16.39	80.99

Determination of optimum bitumen content for SDBC mixture is done by using bitumen content according to the MoRTH's specification which is 5.0%, 5.5% and 6.0%.

TABLE 5
Results of SDBC Mix for Varying Percentage of CR

CR	Bitumen Content	Marshall Stability Value	Flow value	Bulk density of the mix	Air voids	VMA	VFB
		S	F	G_m	V_V		
%	%	kg	mm	gm/cc	%	%	%
6	5.0	1069.67	3.04	2.42	3.58	14.64	75.54
6	5.5	1158.33	2.79	2.42	3.44	14.47	76.21
6	6.0	1196.77	2.55	2.43	3.22	14.22	77.32

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 05, May-2016

TABLE 6
Determination of Marshall Stability (S) and Flow Value (F) for SDBC

Bitumen content	Marshal stability value (S) kg	Flow value (F) mm
5	736.64	3.26
5.5	843.65	3.77
6	963	4.13

TABLE 7
Determination of Bulk Density (G_{mb}), Air Voids (V_v), VMA and VFB for SDBC

Bitumen Content	Bulk Density of the mix	Theoritical Specific Gravity of the mix G_t	V_V	V_b	VMA	VFB
%	gm/cm³		%	%	%	%
5	2.41	2.50	3.78	11.24	15.03	74.81
5.5	2.40	2.48	3.49	12.26	15.76	77.80
6	2.39	2.47	3.1	13.28	16.39	80.99

IV. CONCLUSION

- The aim of the study was to utilize the waste materials i.e. crumb rubber waste for mass scale utilization such as in highway construction in an environmentally safe manner.
- As in the first part of the study, an attempt was made to assess the stabilization of the bitumen containing crumb rubber waste in shredded form by performing basic tests such as Ductility Test, Penetration Test, Softening Point Test, Viscosity Test and Flash & Fire Point Tests.
- On the basis of the performance of the modified bitumen, the range of optimum percentages of crumb rubber waste were selected for further investigations related to Bituminous Concrete Mixes such as Semi Dense Bituminous Concrete (SDBC).
- Marshall Values, namely Marshall Stability Value, Marshall Flow Value, Air Voids, Voids in Mineral Aggregates and Voids Filled with Bitumen, determined from Marshall Stability Test, serve as the benchmark values to assess the quality of Bituminous Concrete.
- The design and performance of Bituminous Concrete mainly depends upon the quality and percentage of binder used.

Characterization of Materials and Stabilization of Mix

- The present stabilization process is very effective in controlling the environmental pollution, because the waste materials were completely recycled without any adverse impact on the environment. This study also encourages the mass scale utilization of crumb rubber waste for Highway Engineering Applications.
- The results of the study indicated that the modified mixture have a better results compared to the non-modified mixtures. By adding crumb rubber to the bitumen a better binding between binder and aggregates was obtained.
- As crumb rubber content increases, Marshall Stability Values also increase, which shows that the modified mix is durable and long lasting. It is also observed that the maximum quantity of crumb rubber waste, which could be added in Bitumen, is up to 12%. The addition of crumb rubber waste beyond 12% results in the segregation of crumb rubber particles.

Improvement in the Properties of Bitumen

- From the laboratory work, an alternate use of crumb rubber is under study where crumb rubber is mixed with bitumen and used for preparing the mix. The mix was used to study the basic properties of bitumen like penetration value, ductility value and softening point. The crumb rubber blended bitumen is subjected to different tests as discussed above. Here 80/100 penetration grade bitumen was taken and it was modified with different percentage of crumb rubber in small pieces of 3 to 5 mm starting from 4% to 12%. From the results, the maximum percentage of crumb rubber as bitumen modifier was in the range 10 - 12% by the weight of binder content.
- It was observed that values of penetration and ductility are reduced by 14.56% and 24.49 % respectively, by the addition of 12% crumb rubber waste.
- Softening Point, Viscosity, Flash and Fire Point were found to be increased by 19.64 %, 63.5%, 11.94% and 13.51% respectively, by the addition of 12% crumb rubber waste.

Improvement in the Properties of Bituminous Concrete Mixes

- After obtaining the data from the Marshall test and the data analysis, it was found that the crumb rubber modified sample was able to resist deformation in a better way as compared to the conventional sample. The result clearly shows that the rates of deformation in crumb rubber modified mix are better than the conventional mix.. The binding property of cr makes the sample to last longer as it also improves the stripping value of the aggregates. Hence, this technology will result lesser road repairs and using crumb rubber will help to utilize non biodegradable waste.
- The presence of crumb rubber reduces the air voids which prevents the moisture absorption and also prevents oxidation of bitumen due to entrapped air. This result shows enhancement of Marshall Stability value, stripping and other design parameters and this may prevent formation of potholes.
- Crumb rubber content for Semi Dense Bituminous Concrete (SDBC) was found to be 6%.
- Crumb rubber content Bulk Density of SDBC increases by 1.03%.
- Crumb rubber content Percent Air voids in SDBC mixes reduces by 20.75%.
- Crumb rubber content Percent Voids in mineral aggregates (VMA) of SDBC mixes reduces by 5.34%.
- Crumb rubber content Percent Voids filled with bitumen (VFB) of SDBC mixes is increased by 5.72%.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 05, May-2016

- Overall, using the crumb rubber in bituminous mixture helps to:
  - Utilization of crumb rubber waste.
  - Reduction in the use of bitumen by around 10%.
  - Increase in the strength and performance of the road.
  - Provide better adhesion between the asphalt and the aggregate.
  - Avoid the use of anti-stripping agents.
  - Reduce the cost.
- Avoid disposal of crumb rubber waste by incineration and land filling.
- Add value to crumb rubber waste.
- Creating jobs and source of income for rag pickers.
- Develop a technology, which is eco-friendly.

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