PAVEMENT REHABILITATION USING FOAM BITUMEN STABILIZED MATERIALS (BSM)

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The asphalt paving industry is constantly exploring technological improvements that will enhance the material's performance, increase construction efficiency, conserve resources, and advance environmental stewardship. In a developing country like India, energy savings, conservation and optimum use of pavement materials are important issues, specially for petroleum and mineral products. There is a need for immediate attention towards the implementation of sustainable and environment friendly pavement construction technologies. Application of such technologies will lead to the efficient use of existing and waste materials without creating problems to the environment and at the same time achieving the required pavement quality and performance. Recent advances in asphalt technology around the world have made cold recycling an increasingly popular and cost effective pavement construction and maintenance technique. India has also started adopting sustainable road construction technologies like warm mix asphalt, cold mix asphalt and recycling of asphalt pavements.

This paper presents the feasibility of producing high quality cold recycled asphalt using foam bitumen for a heavily trafficked National Highway of India. Foam bitumen stabilization was used to rehabilitate the existing base layers of pavements incorporating thick asphalt layers, resulting in higher percentages of Reclaimed Asphalt Pavement (RAP) in the mix. Foam mix design and pavement design was carried out as per IRC 37: 2012. Energy conservation and reduction in GHG emissions were also monitored during the construction phase. The knowledge gained from this research is intended to improve current mix design and structural design practices and to develop data base for adopting sustainable pavement construction technologies in India.

1.0 INTRODUCTION

Rapid growth in industrial development and economy in last two decades has demanded upgradation of existing road network in the country. A good road network is a vital infrastructure requirement for rapid economic growth. There is a huge road network in the country but it is still inadequate to meet the accessibility and mobility requirements. Severe distresses that occurred in existing road network required that the bearing capacity of the existing pavements should be increased.

The conventional method of providing bituminous surfacing on flexible pavements requires significant amount of materials and energy. Therefore, in order to reduce consumption of fuel and aggregates, pavement recycling technology may be adopted for Indian roads (Reddy et al., 2013). Also, there is a problem of the scarcity of aggregates, which forces truck delivery of materials from long distance. The use of diesel for running these trucks contributes to emission of pollutants such as particulate matter, nitrogen oxides, carbon dioxides and sulphur dioxides. Many of the diesel engine emissions have been identified as carcinogenic, and harmful to the human health, even at occupational and environmental levels of exposure. For a lead of 200 km (which is common in north India), it will require 18 million liters of diesel in transportation alone (Veeraghan and Mallick, 2010). Therefore, a serious attempt has to be made to develop and adopt alternative technologies for road construction and maintenance to reduce consumption of fuel and aggregates. Recycling of existing bituminous pavement materials to produce new pavement material results in considerable savings of material, money and energy.

One of the most energy efficient mechanisms for rehabilitation of an asphalt pavement is cold in place recycling (CIR). It involves recycling of asphalt pavement without application of heat during the recycling process. CIR is carried out on site and generally uses 100 percent of the RAP (reclaimed asphalt pavement). Bitumen stabilized materials (BSMs) incorporating bitumen emulsion or foamed bitumen, have been used globally over the last two decades to provide base layers for many thousands of kilometers of road pavements (Oluwaseyi, 2010 and Kandhal, 2011). The BSM technology using foam bitumen is primarily applied on rehabilitation projects using recycled materials in the existing pavement. Foamed stabilization technique needs less binder and water compared with other types of cold mixing, therefore, the cost of transportation and asphalt binder are reduced (Khalid, 2013).

Foamed bitumen is a mixture of very hot bitumen and water. It is produced by injecting water into hot bitumen (160–180°C) which is supported by air. The volume of water is between 2–5% of the volume of bitumen. When the water contacts the hot bitumen, it rapidly changes to steam and the volume of bitumen expands many times. In this stage the foamed bitumen is produced, it contains thousands of bitumen bubbles and then is ready to be mixed with an aggregate (Thom, N., 2008). Many factors affect the strength and durability of foamed bitumen treated materials, such as binder content, active filler type and content, aggregate composition and gradation, moisture content, compaction effort, and curing regime (Fu et al., 2008; Fu et al., 2009; Jitareekul & Thom, 2009; Nataatmadja 2001; Marquis, 2003).

This paper presents the feasibility of producing high quality cold recycled asphalt using foam bitumen for a heavily trafficked national highway in India.

2.0 NH-2 REHABILITATION PROGRAM

The subject project road passes through many important cities/towns of historical, tourist, and commercial interest on national highway number 2 (NH-2). The section of the project road is part of national highway which connects Delhi, the national capital to Kolkata. The project road is about 85 kms in length. The road section developed heavy distresses/defects and the pavement was deteriorated severely and showing signs of distress and premature failure, especially in the form of severe rutting, cracks and deformation. Photo 1, 2 and 3 shows the condition of the distressed pavement.

Photo 1: Severe rutting on NH 2

Photo 2: Pavement condition

Photo 3: Map Cracks

3.0 FIELD INVESTIGATIONS

Field investigations like: test pit observations, coring of bituminous mixes, classified traffic volume survey, collection of milled material were taken up during August 2016. Test pits were excavated right upto the subgrade level to examine the construction quality of constituent pavement layers including the earthwork/subgrade. In-situ field densities of Subgrade soil, Granular sub base (GSB) and Granular base course (Wet Mix Macadam) were determined by sand replacement method, as per IS standard test procedure. As regards the field densities of Dense Bituminous Macadam (DBM) and Bituminous Concrete (BC) layers, a number of cores, from different locations, in addition to the bituminous materials (chunks) collected from various test pits, were sampled for the purpose of detailed laboratory evaluation. The thickness of each constituent pavement layers was measured at various locations. Cores, chunk material and RAP material were evaluated in detail in laboratory at CRRI, New Delhi

Based on field and laboratory testing results of the sub-grade and the planned traffic design, if the pavement had to be reconstructed, the conventional pavement design of the whole pavement would be as follows:

Layer Specification	Thickness,mm, 185 MSA
Granular Sub Base (GSB)+ Granular Base (WMM)	450
Dense Bituminous Macadam (DBM)	185
Bituminous Concrete (BC)	50

4.0 RAP MIX DESIGN USING FOAM BITUMEN

With the aim of recycling the existing pavement layers and at the same time strengthening the aged and distressed pavement, Cold in situ recycling using foamed bitumen approach was considered. The milled (RAP) material was evaluated in CRRI laboratory for RAP mix design.

Bitumen and Foam Characterization

VG-30 grade bitumen was used and its physical properties are presented in Table 1.

Table 1 Physical properties of the bitumen VG30

S.No	Test	As per IS	Results obtained	MoRTH specification
1	Specific Gravity at 27 °C	IS 1202	1.01	0.99 (min)
2	Ductility at (27 °C, cm)	IS 1208	100+	75 (min)

S.No	Test	As per IS	Results obtained	MoRTH specification
3	Softening point, $^{\circ}$C	IS 1205	50	35-50
4	Penetration at 25 $^{\circ}$C, 100g, 5 sec. 1/10th mm	IS 1203	65	60-70
5	Viscosity, 60 $^{\circ}$C, poises, min	ASTM D4402	2726	2500
6	Viscosity, 135 $^{\circ}$C, poises, min	ASTM D4402	7.62	4.50

Injection of cold water and air with varying pressure into hot bitumen produces foamed bitumen. This bitumen foaming process is tested to find out optimum percentage of foaming water content and bitumen temperature, for producing best foam by gaining maximum ER (expansion ratio) and HL (half life). For obtaining the mix design, Wirtgen WLB 10S foaming equipment has been used for foaming of bitumen at the prefixed set conditions of air pressure at 500kpa and water pressure at 550kpa. The optimum water addition is chosen as an average of two water contents required to meet minimum criteria of ER $\geq$ 8 and HL $\geq$ 6 seconds (as specified by TG-2, 2009; Wirtgen, 2012).

Foaming experiment is conducted at two different asphalt temperatures and three different water contents ranging from 3 to 7% by weight of bitumen with an increment of 2%. Table 2 shows the ER and HL measured at varying water contents ranging and temperature. The best foam was observed at temperature of 180°C and at a foaming water content of 5%, which has been used for mix design. Results show that expansion ratio increases and half-life decreases with increase in water content.

Table 2 Optimum Expansion Ratio and Half Life at different Binder Temperature and Water Content

Temperature (^{0}C)	Water content, (%)	ER, (%)	HL, (sec)
170	3	6	16
	5	12	15
	7	16	8
180	3	8	14
	5	14	12
	7	18	10

Preparation of Foam Mix

Several agencies developed guidelines for mix design of cold recycled foam mixtures, based on laboratory tests, empirical formulae or past experience with identical projects (TG 2, 2009; CalTrans, Wirtgen, 2012). OPC cement grade 43 and stone dust was blended with 80% of RAP material by weight of total mix to meet the gradation requirement of IRC 37: 2012. Optimum Moisture Content (OMC) of the untreated blended materials was determined using the moisture-density relationships according to AASHTO T180 (2010). This pre-wetting water content was added to get better dispersion of foam in the mix. The sample of minimum 10 kg of material was prepared and mixed at particular Foamed Binder Content in Wirtgen WLM 10 pug mill mixer.

Different batches of mix were prepared by varying the foam bitumen content from 2.0% to 3% by weight of aggregate. The main advantage of foamed mixes is that it contains lesser binder content. This is almost 50% less when compared with HMA. Upon mixing, samples were prepared using Marshall compactor. Compacted mix was then cured for 72hrs at 40°C in an oven. Six numbers of specimens were manufactured from each batch in which three were tested for ITS dry and other three for ITS wet after cooling them to 25°C according to ASTM: D6931-12.

Compaction characteristics of untreated bitumen mixes were evaluated according to Modified Proctor Test. With increasing moisture content, dry density values increased to a maximum and then decreased. Maximum dry density is obtained at 6% moisture content, which is known as Optimum moisture content.

Performance Testing

To assess the durability and performance of bituminous mixes of recycled foam mix, several laboratory tests are conducted. Marshal samples were prepared and tested as given below:

Dry and Wet Indirect Tensile Strength

Indirect tensile strength test is useful to evaluate resistance of compacted bituminous mixture to cracking. These specimens were tested for their tensile strength at 25°C. The failure load was recorded and the indirect tensile strength (St) was calculated using equation (1)

$$S_t = \frac{2P}{\pi Dt} \text{ ....Eq. (1)}$$

Where, P is the load (kg), d is the diameter in cm of the specimen; t is the thickness of the specimen in cm. To check the moisture resistance of foam mix, wet ITS was also obtained. The conditioned specimens were placed in a water bath maintained at 25°C for 24 hours before performing the ITS.

Variation of the dry ITS and wet ITS values of foamed mix at different foamed binder content are presented in Figure 1. As per IRC: 37-2012, minimum requirement of Dry ITS and Wet ITS is 225 and 100kPa respectively. With increasing the foam binder content, dry ITS value increases up to certain extent and then further decreases. At lower binder content, binder is just not sufficient to provide proper lubrication during compaction. However at higher binder contents, more lubrication provided decreases the dry ITS.

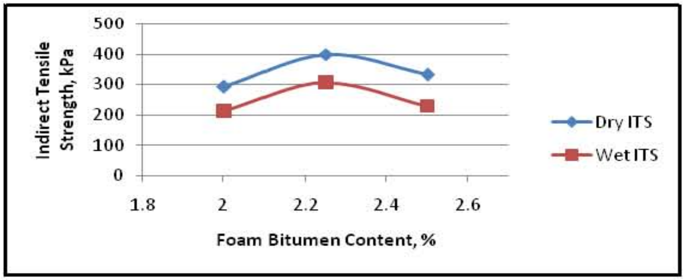

Figure 1 Variation of Dry and Wet ITS with Foam Bitumen Content

To identify whether the coating of bitumen binder and aggregate is susceptible to moisture damage, Tensile Strength Ratio (TSR) is determined according to ASTM D 4867 (2009). The specimens are compacted to a void content of 7 %, which corresponds to void levels expected in the field. TSR is the ratio of average indirect tensile strength of conditioned specimens to the unconditioned specimens. Unconditioned specimens are maintained at room temperature and then adjusted to 25C. The conditioned specimens were placed in a water bath maintained at 60°C for 24 hours and then placed in an environmental chamber maintained at 25°C for two hours. Then tensile strength of each specimen is determined by the tensile splitting test. The Tensile Strength Ratio (TSR) of specimen is computed by equation (2).

$$TSR = \frac{T_{wet}}{T_{dry}} * 100 \qquad \text{... ... ... Eq. (2)}$$

Where, T_{wet} is average indirect tensile strength of conditioned specimens and T_{dry} is indirect tensile strength of unconditioned specimen.

Table 3 shows the Tensile Strength Ratio at different binder contents. Maximum TSR value is obtained at 2.25% foamed binder content.

Table 3 Tensile Strength Ratio Values

Sample No	Tensile Strength Ratio, %		
	2.0% Foamed Binder Content	2.25% Foamed Binder Content	3.0% Foamed Binder Content
1	73.8	77.4	69.4
2	70.1	75.2	71.4
3	74.3	76.5	66.3

Resilient Modulus Test

This test is used to analyze the pavement response for the repeated traffic loading by measuring the indirect tensile strength modulus according to ASTM D7369 (2011). The test is performed on Universal Testing Machine (UTM-16). Specimens prepared at their optimum binder content were loaded by diametrical force in pulse loading. Test parameters were; Haversine Load Pulse, condition pulse count of 5, pulse width of 250 ms, peak loading force of 500N and poisons ratio of 0.35.

Table 4 shows the Resilient Modulus at 25°C and 35°C for different binder content. It can be seen from table 4 that maximum MR values are obtained at 2.25% foamed binder content at both the temperatures.

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Table 4 Resilient Modulus Values

Resilient Modulus, MPa (average of 3 tests)					
2.0% Foamed Binder Content		2.25% Foamed Binder Content		3.0% Foamed Binder Content	
25°C	35°C	25°C	35°C	25°C	35°C
1552	1034	2577	1444	2319	1550

The final recommendation for RAP mix design was for 2.25% foam bitumen and 6% optimum moisture content. Optimum foaming characteristics were achieved at temperature of 180°C and foaming water content of 5%. This combination for foaming was selected for the VG-30 asphalt binder in mix design. 1% cement OPC 43 grade was added to improve the stability and better dispersion of foamed bitumen in fine particles of the mix.

5.0 PAVEMENT DESIGN

The design traffic in terms of Cumulative Standard Axles (CSA) was worked out by considering the commercial traffic and their vehicle damage factor (VDF), for a convenient design life duly accounting for the anticipated traffic growth. In the present case, the cumulative standard axles have been worked out for 15 years design life by assuming an annual growth rate of commercial vehicles as 5%. IITPave software was used to carry out the pavement design as per IRC 37:2012 with 90% reliability performance.

The value of resilient modulus of BSM ranges from 600-1200 MPa as per Sec 7.3.3 of IRC-37:2012 and it is recommended to use the value of 600 MPa for structural design purpose. BSM is sensitive to moisture, a safer value of 600 MPa is to be adopted for structural design as per the code. However, in the present study, as per the values given in table 4, in laboratory much higher values of Resilient modulus were achieved. Keeping in view the satisfactory values of TSR (tensile strength ratio) obtained from test results, which is indicative of a good moisture resistance property of BSM mix, a mid value of resilient modulus 800 MPa is assumed for BSM layer for structural design purpose. The stiffness modulus obtained in laboratory for the BSM at 35°C and 2.25% foamed binder content is 1444 MPa. Considering an average wet ITS value of 306 KPa, however, a conservative value of 800 MPa is considered safe in the pavement design under the adopted design parameters (i.e., 2.25% binder and 6% OMC).

The crust composition is given in Table 5.

Table 5: Crust composition with 800 MPa E value for BSM layer

Layer Specification	Thickness,mm185 msa, 15 years
Granular Sub Base (GSB)+ Granular Base (WMM)	450
Foam Bitumen Stabilized Base (BSM) (recycled layer)	175
Dense Bituminous Macadam (DBM)	70
Bituminous Concrete (BC)	50

6.0 CONSTRUCTION PROJECT

Project evaluation was the first step in the construction process. Necessary comprehensive site investigation was conducted in order to check and qualify the quality and quantity of RAP that will be processed for recycling procedure. Laboratory investigation of the asphalt foaming characteristics, mix design and pavement design were completed prior to start of the construction.

Wirtgen milling machine was used for milling top 40mm layer of BC and transported to hot mix plant for further use during overlay. The existing DBM layer was to be recycled using foam bitumen. Photo 4 shows the surface after milling. Fresh crusher dust was spread over the milled surface (as per the gradation requirement) (Photo 5) and then spreading of cement was done (Photo 6). Photo 7 shows the homogeneously spread fresh aggregate and cement.

Photo 4: Surface after milling

Photo 5: Crusher Dust spread over milled surface

Photo 6: Spreading of cement

Photo 7: Surface after spread of cement on fresh aggregate

Photo 8: Cold in situ recycling taking place

WR240 machine (Photo 8) was used for recycling at NH2 project. The foam mixing recycler is coupled with a bitumen supply tank and water supply tank. The recycler pushes the tanker. Heated bitumen at 180°C is transported from hot mix plant to construction site through a temperature controlled tank. Hot bitumen and water gets injected in to the recycler and foaming takes place through spray bars. The foamed bitumen then gets mixed with the pulverised pavement material. Immediately following this recycler was Hamm roller to compact the recycled base (Photo 9). After grading and profiling of the recycled base layer (Photo 10), steel drum roller was used to seal the top layer. The compaction was then followed with curing process prior to overlay. The recycled surface is cured for 48-72 hours by sprinkling of water at an interval of 6-7 hours.

Photo 9: Rolling operation

Photo 10: Grading and profiling

Photo 11 shows the view of recycled surface before overlay and photo 12 shows the view after the overlay.

Photo 11: Recycled surface before overlay

Photo 12: Recycled road after overlay

7.0 CONCLUSIONS

The addition of cement would result in increased strength properties of mixes. The indirect tensile strength (ITS) and tensile strength ratio (TSR) values of recycled mix were found to be more than satisfactory whereas resilient modulus (MR) values achieved were significantly higher than the specified values (as per IRC37:2012). Cold recycled materials are good opportunity to save money and resources. The recycling process resulted in construction time saving, minimal use of virgin aggregates, less transportation of materials and several other environmental benefits. Huge reduction in carbon emissions can be achieved with the use of RAP technology.

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