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DESIGN OF COLD RECYCLING MIXES USING EMULSION/FOAMED BITUMEN

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Abstract

In the recent years Recycling technique is gaining popularity due to speedy in construction and maximum percentage utilization of existing pavement. However, the suitability of recycling generally depends on the condition of the existing pavement, asphalt content and aggregate gradation of existing composition of bituminous layer. This paper focuses on the development of a mix design method for foamed bitumen mixes with effective use of RAP (Reclaimed Asphalt Pavement). For the mix design and design of pavement existing pavement material will be checked to find its suitability for recycling and fixed the gradation as per MORTH specifications by adjusting missed fractions. After adopting the final gradations mixes will be prepared using foam bitumen and tested in the laboratory. Finally, using the properties of recycled mixes an alternative pavement crust will be suggested in place of conventional bituminous pavements.

Introduction

Recycling of Reclaimed Asphalt Pavements (RAP) is required to be used for technical, economical and environmental reasons. Use of RAP has been favoured all over the world over virgin materials in the light of the increasing cost of the bitumen, the scarcity of quality aggregates and the pressing need to preserve the environment. The use of RAP also decreases the amount of waste produced and helps to resolve the disposal problem of highway construction materials. Reclaimed Asphalt Pavements contain best quality aggregates and they can be effectively improved with foamed asphalt/bitumen emulsion along with fresh aggregates and crusher dust to impart necessary strength for a durable pavements.

1.1 Main objectives of the study

- Cold-mix recycling allows the reuse of existing pavement materials resulting in the conservation of existing resources. The resources conserved include aggregate and petroleum resources, and fuels from reduced transportation and processing requirements (no heating of materials required). The reuse of the existing asphalt concrete pavement materials also eliminates the problem of disposal which can be an environmental as well as an economic concern.
- A cold-mixed recycled pavement should, in most instances, have a wearing surface applied to it. The recycled pavement will normally require form 3 to 30 days to cure before a wearing surface or another recycled layer is placed on top. The strength developed in the cold-mix recycled pavement will typically be slightly less than that of a conventional new asphalt concrete pavement.

1.2 Scope of the work

The scope of the work includes Design of cold recycling mixes, finding resilient modulus using empirical relations and pavement design. The pavement design was done by using IITPAVE for different trails i.e considering different thicknesses of Pavement. The cost comparison for a typical two lane road is also assessed.

GRADATION

1.3 Sampling

Good practice for sampling aggregate applies to the sampling of RAP. Samples may be obtained during production or from a stockpile. Contractors should prepare a plan for sampling and testing RAP. The sampling plan should meet the minimum testing frequency requirements specified by the owner (i.e., State transportation department, highway agency, etc.) and should detail the procedure used to obtain representative samples throughout the stockpile for testing.

1.4 Aggregate gradation

The first step that was done is the gradation of aggregate present in RAP sample and comparing the RAP gradation with the gradation given in Table 500-19 of MoRTH fifth revision. For this process has to be done, the bitumen present in the RAP has to be removed. Bitumen extraction in the RAP material was done by using Bitumen Extractor. The following procedure adopted for the gradation process.

The RAP sample present in all the bags opened and laid on the floor. Then the RAP sample is mixed thoroughly and uniformly. The sample was divided in to four equal quarters. 1 KG of sample is taken from each quarter. The four samples were kept in the Oven for 24hrs at 110^{o}C. This action was done to dry the sample and free it from any moisture present in the sample. The ignition oven may change the physical characteristics of some aggregates. In general, RAP aggregates must meet the same quality requirements specified for virgin aggregates. The care should be taken for this.

Bitumen extraction was done by using Bitumen extractor apparatus. The procedure is done as given below. The same procedure was followed for all the four samples.

- Take the first sample and place in the bowl of extraction apparatus.
- Add benzene to the sample until it is completely submerged.
- place the Filter paper over the bowl of the extraction apparatus containing the sample.
- Clamp the cover of the bowl tightly.
- Place a beaker/collecting bottle under the drain pipe to collect the extract.
- Sufficient time is allowed for the solvent to disintegrate the sample before running the centrifuge. Bitumen Extractor.
- Run the centrifuge slowly and then gradually increase the speed to a maximum of 3600 rpm.
- Maintain the same speed till the solvent ceases to flow from the drainpipe.
- Run the centrifuge until the bitumen and benzene are drained out completely.
- Stop the machine, remove the cover and add 200ml of benzene to the material in the extraction bowl and the extraction is done in the same process as described above.
- Repeat the same process not less than three times till the extraction is clear and not darker than a light straw colour.
- Collect the material from the bowl of the extraction machine and dry it to constant weight in the oven and cool to room temperature.

Proper care should be taken in such a way that the process of Bitumen extraction was done in its full way i.e the entire Bitumen present in the RAP sample was removed and the sample is ready for the next process i.e gradation of aggregate.

Gradation of Aggregate was done by using sieve analysis test. Sieve analysis helps to determine the particle size distribution of the coarse and fine aggregates. This is done by sieving the aggregates as per IS: 2386 (Part I) – 1963. In this we used different sieves as standardized by the IS code and then pass aggregates through them and thus collect different sized particles left over different sieves. The Procedure to determine particle size distribution of Aggregates was done as follows.

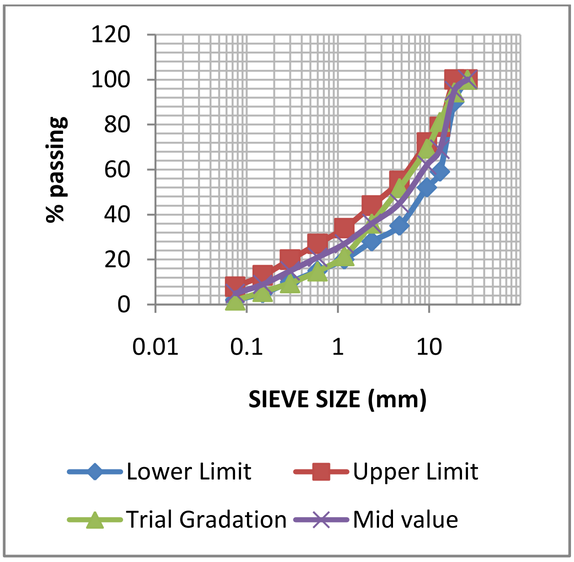
The test sample is dried at a temperature of 110°c and weighed.

- The sample is sieved by using a set of IS Sieves.
- On completion of sieving, the material on each sieve is weighed.
- Cumulative weight passing through each sieve is calculated as a percentage of the total sample weight.
- Fineness modulus is obtained by adding cumulative percentage of aggregates retained on each sieve and dividing the sum by 100.

The values of combined gradation i.e mixing of 10 percent 20mm aggregate and 90 percent of aggregate obtained after extracting bitumen from RAP material is shown in the below table.

Table 0.1 Combined gradation values obtained after addition of virgin aggregates.

Sieve size (mm)	20 mm	Gradation of the Sample	Combined Gradation	Lower Limit	Upper Limit	Mid value
26.5	100	100	100	100	100	100
19	89	95	94	90	100	95
13.2	29	87	81	59	79	69
9.5	5	77	69	52	72	62
4.75		58	52	35	55	45
2.36		40	36	28	44	36
1.18		24	22	20	34	27
0.6		16	15	15	27	21
0.3		11	10	10	20	15
0.15		6	6	5	13	9
0.075		2	2	2	8	5



Graph 0.1 Comparison of results obtained from sieve analysis with MORTH values

The red line in the graph shows the upper limit of the percentage passing aggregate, the blue line in the graph shows the lower limit of the percentage passing aggregate as per Table 500-19 of MORTH fifth revision. and the violet line shows the mid/average values of the upper and lower limit values of Table 500-19 of MORTH fifth revision. The green line is the lined formed from the results of sieve analysis (10% of 20mm virgin aggregate and 90% of aggregate obtained after extracting bitumen from RAP material). The green line should lay in between Red (Upper) and Blue (Lower) lines to satisfy the MoRTH standards. Now we can see that the green line is in between Upper and lower limit lines. hence we can conclude that this combination (10% of 20mm virgin aggregate and 90% of aggregate obtained after extracting bitumen from RAP material) is as per standards given in Table 500-19 of MORTH fifth revision.

COLD RECYCLING MIX DESIGN

1.5 Preparation of foamed bitumen

Foamed Bitumen is produced by injecting water into hot bitumen resulting in instantaneous foaming. The injected water turns in to steam which is enclosed by finely divided bitumen bubbles. The foamed bitumen is injected in to the cold RAP mixes or fresh aggregates treated with foamed bitumen. The properties such as binder used for foaming, viscosity of foamed bitumen etc play an important role in the quality of the mix. The step by step procedure for preparation of foamed bitumen is as follows.

- The required quantity of bitumen is heated at 170°C in a kettle.
- Water is added to the bitumen (1% weight of bitumen).
- Foam is formed after addition of water to the heated bitumen.
- The sample is thoroughly stirred.
- This foamed bitumen is added to RAP (RAP+Cement+Virgin Aggregate).

Before the preparation of the foamed bitumen the following step has to be carried out.

- 1200g of sample is taken which includes RAP, virgin aggregate and cement (1056g of RAP, 24g of Cement filler, 120g of 20mm virgin aggregate).
- Foamed bitumen of 1%, 2% & 3% had added to the above sample.

1.6 Preparation and testing of Marshall Sample

The mixing moisture content (MMC) of a foamed bitumen mix is moisture content in the RAP mix when foamed bitumen is injected which is practically same as compaction moisture content (CMC) required for maximum compaction. A few trials are needed to determine the MMC. Methods of sample preparation and curing are same as that of the bitumen emulsion mixes. Mixes are prepared with different amount of foamed bitumen and that which meets the minimum strength requirement in dry and wet condition is adopted for production of foamed mixes. The step by step procedure for preparation and testing of Marshall sample is given below.

- The mixture of foamed bitumen and RAP was filled in mould with 100mm dia and 63.5mm height.
- These samples are compacted by applying 75 blows with marshal compaction hammer on either side.
- Dry and Wet curing of specimens was carried out on prepared samples. For Dry curing, specimens were kept at 40°C for 72hrs. For Wet curing, specimens were immersed in water for 24hrs at 25°C.

Figure 0.1 Marshall Samples before testing

- Indirect tensile strength test was carried out on the specimens in a standard Marshal loading frame.

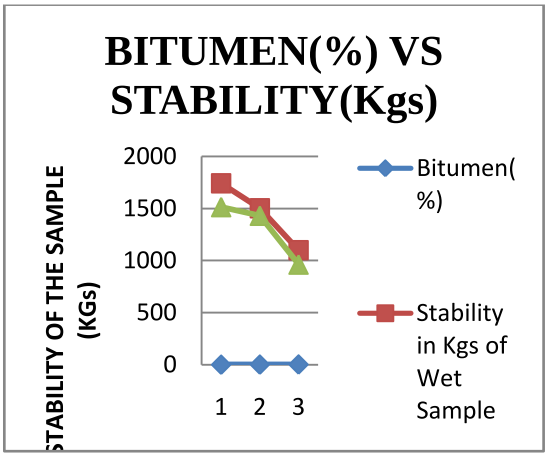
Figure 0.2 Sample during Testing

Results and analysis

Table 0.1 Average Stability of the samples.

Bitumen(%)	1%	2%	3%
Average Stability in Kgs of Wet Sample	1743	1505	1101
Average Stability in Kgs of Dry Sample	1514	1431	963

As stability of sample is decreasing with increasing in bituminous percentage, it can be concluded that 1% Bitumen is sufficient for RAP mix. The same is depicted in the following graph.



Graph 0.1 Showing the Variation of stability with Bitumen Percentage

1.7 Calculation of Tensile strength of the sample

The Tensile Strength of the sample is given by the formula

St = (2000Xf)/(3.14XdXh)

where, St is Tensile Strength, KPa
f is load in Newton.
d is diameter of specimen in mm.
h is height of specimen in mm.

by inserting d as 100mm & h as 63mm in the above equation

The Tensile Strength of the Sample(S_t) is 0.002 KPa.

1.8 Calculation of resilient modulus

Regression Equation for obtaining Resilient Modulus as per IRC:37 is

M_R = 1.1991 X ITS + 1170

where M_R is Resilient Modulus in MPa
ITS is Indirect Tensile Strength in Kpa
ITS has to be determined in the marshal loading

by inserting the ITS value obtained from Marshal Test in the above equation the **Resilient Modulus of the sample(M_R) is 1172Mpa.**

1.9 Design guidelines and methodology

Procedure given in Section 10.4 and Annex-IX of IRC: 37-2012 will be followed for this pavement design.

Methodology:
In order to provide scientific design thickness 'Mechanistic – Empirical pavement design' procedure is followed as directed in IRC: 37-2012 with the help of **IITPAVE software**. The in-put parameters considering in design of

pavement will be derived as given in the following table.

PAVEMENT DESIGN BY USING IITPAVE

1.10 Pavement model

A flexible pavement is modelled as an elastic multilayer structure. Stress and strains at critical locations (shown in figure. 5.1) are computed using a linear layered elastic model. The stress analysis software IITPAVE has been used for computation of stresses and strains in flexible pavements. Tensile strain $\varepsilon_{t,}$ at bottom of the bituminous layer and the vertical sub grade strain $\varepsilon_{v,}$ on the top of the sub grade are conventionally considered as critical parameters for pavement design to limit cracking and rutting in the bituminous layers and non-bituminous layers respectively. The computation also indicates that tensile strain near the surface close to the edge of a wheel can be sufficiently large to initiate longitudinal surface cracking followed by transverse cracking much before the flexural cracking of the bottom layer if the mix tensile strength is not adequate at higher temperatures.

Any combination of traffic and pavement layer composition can be tried using IITPAVE. The designer have full freedom in the choice of pavement materials and layer thicknesses. The traffic volume, number of layers, the layer thickness of individual layers and layer properties are the user specified inputs in the program, which gives strains at critical locations as outputs. The adequacy of design is checked by the program by comparing these strains with allowable strains as predicted by the fatigue and rutting models.

1.11 DESIGN STEPS

- The elastic modulus values of the materials proposed to be used in various layers are explained above.
- Tentative thickness values of pavement structure are assumed.
- The tensile strain at bottom of BT layer and the compressive strain on the top of the subgrade layer are calculated using IITPAVE software.
- The strain values from IITPAVE software are then substituted in the equations given below and the pavement design life in terms of MSA is estimated using Fatigue and Rutting criterion and vice versa.

1.11.1 Fatigue Model:

considering Vb of 11.8% and Va of 4%, the fatigue equation has been worked out for 90% reliability as per procedure suggested in annex-i of irc 37-2012 and is provided below. The Rutting equation is

$$N_f = 0.5161 \text{ x } C \text{ x } 10^{-04} \text{ x } (1/\varepsilon_t)^{3.89} \text{ x } (1/M_R)^{0.854}$$

$$C = 10^M \text{ and } M = 4.84(V_b/V_a+V_b-0.69)$$

Where

N_f = No. Cumulative standard axles to produce 20% & 10% cracked surface area for 80% and 90% reliability respectively.

ε_t = Tensile Strain at the bottom of BT layer.

M_R = Resilient modulus of BT layer (MPa).

V_a = Volume of air voids in the bituminous mix.

V_b = Volume of bitumen in the bituminous mix.

The Fatigue equation for 90% reliability is

$$N_f = 0.972 \text{ x } 10^{-04} \text{ x } (1/\varepsilon_t)^{3.89} \text{ x } (1/M_R)^{0.854}$$

1.11.2 *Rutting Model:*

The rutting life of pavement will be determined as per clause 6.3 of IRC: 37-2012 for 90% reliability

$N_r = 1.41 \times 10^{-08} \times (1/\varepsilon_v)^{4.5337}$

Where

N_r = No. of Cumulative standard axles.

E_v = Vertical Strain in the sub grade.

The design iteration are continued till the estimated pavement design life in terms of Fatigue and Rutting are more than the design life.

1.11.3 *Design*

Based on the site condition the following was the data used for pavement design. Here the CBR value is used to calculate the Resilient Modulus of Sub grade and Granular layers. The recommended resilient modulus values of the bituminous materials are taken from Table 7.1 of IRC: 37-2012, tentative guidelines for the design of flexible pavements. These values are based on extensive laboratory testing modern testing equipments following ASTM test procedures. The Poisson's ratio of bituminous layer depends upon the pavement temperature and value of 0.35 recommended for temperature up to 35°C and value of 0.5 for higher temperatures.

Higher viscosity of bituminous binders, which can be achieved either by using higher viscosity grade bitumen will improve both rutting and fatigue behavior of the mixes as compared to mixes with normal bitumen. Fatigue life can be further improved by reducing the air voids and increasing the volume of the binder. Low air voids and higher bitumen content may, however include bleeding and rutting, the chances of which are minimized if higher viscosity binder is used in the mix.

- Design Traffic in MSA: 150
- Grade of Bitumen : VG-40
- Borrow area CBR : 15%
- In-situ CBR : 7%
- Effective CBR : 8%
- Reliability level : 90%

Here, the design was done in a four layer system. So, the details of four layers like Elastic Modulus, Poisons ratio, assumed thickness of layers etc has to be filled in the spaced given. The Elastic modulus of various materials was obtained as explained in previous paragraphs except layer-2, which is the RAP layer. This value of Elastic Modulus of RAP layer was obtained by the calculations done after Indirect Tensile Test. Tensile strain ε_t, at bottom of the bituminous layer and the vertical sub grade strain ε_v, on the top of the sub grade are conventionally considered as critical parameters for pavement design to limit cracking and rutting in the bituminous layers and non-bituminous layers respectively. So, these strains are calculated by using IITPAVE. The obtained strain values from IITPAVE are then substituted in the empirical formulas to get the allowable traffic on the designed road.

The screen shot of the Inputs given in IITPAVE is given below.

After putting the input values and pressing the submit button, the Output file is as shown below. The files shows all our input values and output values i.e the strain values at different locations (Critical locations) as required by us. The strain values obtained from the output file are then inserted in the empirical formula to check whether the strains obtained from the IITPAVE is within the allowable limits or not. Here in our case, the strains for the input values we get from the IITPAVE are within the allowable strains.

The screen shot of the Output values obtained from IITPAVE is given below.

The above strain values submitted in Fatigue & Rutting equations and the Actual Strains and allowable strains are compared and checked whether the strains are below the allowable limits or not. If the actual strains are above the allowable strains then the redesign has to be done modifying/increasing the thickness of layers or by increasing the material properties.

The Rutting equation is

$$N_f = 0.5161 \text{ x } C \text{ x } 10^{-04} \text{ x } (1/\varepsilon_t)^{3.89} \text{ x } (1/M_R)^{0.854}$$

$$C = 10^M \text{ and } M = 4.84(V_b/V_a+V_b-0.69)$$

Where

N_f = No. Cumulative standard axles to produce 20% & 10% cracked surface area for 80% and 90% reliability respectively.

ε_t = Tensile Strain at the bottom of BT layer.

M_R = Resilient modulus of BT layer (MPa).

V_a = Volume of air voids in the bituminous mix.

V_b = Volume of bitumen in the bituminous mix.

The Fatigue equation for 90% reliability is

$$N_f = 0.972 \text{ x } 10^{-04} \text{ x } (1/\varepsilon_t)^{3.89} \text{ x } (1/M_R)^{0.854}$$

Table 0.1 Strain values obtained from IITPAVE

Output from IITPAVE	
Tensile Strain at the Bottom of Bituminous Layer (εt) =	1.009E-04
Vertical Strain at the Top of the Subgrade (εz) =	2.845E-04

Table 0.2 Allowable Strains as per IRC Guidelines

Allowable Strains as per IRC Guidelines	
Allowable Tensile Strain at the Bottom of Bituminous Layer (εt) =	1.171E-04
Allowable Vertical Strain at the Top of the Subgrade (εz) =	2.917E-04

In our calculations the Actual strains are below the allowable stress. Hence the design of flexible pavement is safe.

CBR (%)	Traffic (MSA)	BC(mm)	DBM (mm)	RAP (mm)	GL (mm)
8	150	30	50	90	450

The following table shows the results in terms of Traffic. The design traffic is 150 MSA. Allowable Traffic in MSA, Fatigue is 267. Allowable Traffic in MSA, Rutting is 168. Hence the design is safe for the parameters we provided for Pavement Design.

Table 0.3 Results in terms of Traffic

Allowable Traffic	
Allowable Traffic in MSA, Fatigue	267
Allowable Traffic in MSA, Rutting	168
Design Traffic in MSA	150

Table 4.4 Design Pavement Crust Thickness

CONCLUSION

1.12 Conclusions:

A Pavement can be found suitable for Cold Recycling in the following conditions:

i. There is no loss/ less loss of asphalt in the bituminous layers.
ii. The Asphalt in the mix has not lost much of its viscosity.
iii. The aggregates in the mix has have not undergone much abrasion.
iv. The bituminous layers have bitumen rich mix.
v. There are no distresses like ravelling or cracking.
vi. The Consistency of the asphalt mix is uniform.
vii. The Distresses are limited to the top layers of pavement and not continued to the Base Layers.

1.13 Advantages

It is recommended to repair the pavements by Recycling methods, instead of constructing of new pavements. The advantages of the Recycling are:

i. Cost of Construction is very much less than Construction of new pavement or Construction of Overlays.
ii. Conservation of Aggregate and Binders.
iii. Preservation of existing pavement geometrics, thus avoid the requirement of increase in height of kerbs.
iv. Less User Delay, as entire pavement does not need to be blocked for laying the pavement.
v. It is major initiative towards GREEN WORLD, as there is reduction in use of natural resources.

1.14 Recommendations

Cold mix recycling should be implemented in India by MORTH to large extent ASAP because besides reducing carbon footprint, it has significant economic advantages by reusing very costly asphalt binder (bitumen) and aggregates. If "mill and fill" method is adopted in metropolitan India, cold mix recycling becomes necessary so that surplus RAP is not discarded but recycled back on the road.

Besides cost savings, the advantages of cold mix asphalt recycling include significant structural improvement, equal or better performance compared to conventional HMA, and capability to correct most surface defects, deformation, and cracking.

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