RECOMMENDED PRACTICE FOR RECYCLING OF BITUMINOUS PAVEMENTS

Published by:

INDIAN ROADS CONGRESS

Kama Koti Marg,
Sector-6, R.K. Puram,
New Delhi-110 022

June, 2015

Price : ₹535/-
(Plus Packing & Postage)

First Published : June, 2015

CONTENTS

PERSONNEL OF THE HIGHWAYS SPECIFICATIONS AND STANDARDS COMMITTEE

(As on 12th January, 2015)

1.	Das, S.N. (Convenor)	Director General (Road Development) & Special Secretary to Govt. of India, Ministry of Road Transport & Highways, New Delhi.
2.	(Co-Convenor)	Addl. Director General, Ministry of Road Transport & Highways, New Delhi.
3.	Prasad, Vishnu Shankar (Member-Secretary)	Chief Engineer (R) S,R&T, Ministry of Road Transport & Highways, New Delhi.

Members

4.	Basu, S.B.	Chief Engineer (Retd.), MORTH, New Delhi
5.	Bongirwar, P.L.	Advisor, L & T, Mumbai
6.	Bose, Dr. Sunil	Head, FPC Divn. CRRI (Retd.), Faridabad
7.	Duhsaka, Vanlal	Chief Engineer, PWD (Highways), Aizwal (Mizoram)
8.	Gangopadhyay, Dr. S.	Director, Central Road Research Institute, New Delhi
9.	Gupta, D.P.	DG (RD) & AS (Retd.), MORTH, New Delhi
10.	Jain, R.K.	Chief Engineer (Retd.), Haryana PWD, Sonipat
11.	Jain, N.S.	Chief Engineer (Retd.), MORTH, New Delhi
12.	Jain, Dr. S.S.	Professor & Coordinator, Centre of Transportation Engg., Dept. of Civil Engg., IIT Roorkee, Roorkee
13.	Kadiyali, Dr. L.R.	Chief Executive, L.R. Kadiyali & Associates, New Delhi
14.	Kumar, Ashok	Chief Engineer (Retd.), MORTH, New Delhi
15.	Kurian, Jose	Chief Engineer, DTTDC Ltd., New Delhi
16.	Kumar, Mahesh	Engineer-in-Chief, Haryana PWD, Chandigarh
17.	Kumar, Satander	Ex-Scientist, CRRI, New Delhi
18.	Lal, Chaman	Director (Project-III), NRRDA (Ministry of Rural Development), New Delhi
19.	Manchanda, R.K.	Consultant, Intercontinental Consultants and Technocrats Pvt. Ltd., New Delhi
20.	Marwah, S.K.	Addl. Director General, (Retd.), MORTH, New Delhi
21.	Pandey, R.K.	Chief Engineer (Planning), MORTH, New Delhi

22.	Pateriya, Dr. I.K.	Director (Tech.), NRRDA, (Ministry of Rural Development), New Delhi
23.	Pradhan, B.C.	Chief Engineer (NH), PWD, Bhubaneswar
24.	Prasad, D.N.	Chief Engineer (NH), RCD, Patna
25.	Rao, P.J.	Consulting Engineer, Faridabad
26.	Raju, Dr. G.V.S.	Engineer-in-Chief (R&B), Rural Roads, Director Research and Consultancy, Hyderabad
27.	Representative of BRO	(Shri B.B. Lal), ADGBR, HQ DGBR, New Delhi
28.	Sarkar, Dr. P.K.	Professor, Deptt. of Transport Planning, School of Planning & Architecture, New Delhi
29.	Sharma, Arun Kumar	CEO (Highways), GMR Highways Limited, Bangalore
30.	Sharma, M.P.	Member (Technical), NHAI, New Delhi
31.	Sharma, S.C.	DG (RD) & AS (Retd.), MORTH, New Delhi
32.	Sinha, A.V.	DG (RD) & SS (Retd.), MORTH, New Delhi
33.	Singh, B.N.	Member (Projects), NHAI, New Delhi
34.	Singh, Nirmal Jit	DG (RD) & SS (Retd.), MORTH, New Delhi
35.	Vasava, S.B.	Chief Engineer & Addl. Secretary (Panchayat) Roads & Building Dept., Gandhinagar
36.	Yadav, Dr. V.K.	Addl. Director General (Retd.), DGBR, New Delhi
37.	The Chief Engineer (Mech.)	(Shri Kaushik Basu), MORTH, New Delhi

Corresponding Members

1.	Bhattacharya, C.C.	DG (RD) & AS (Retd.), MORTH, New Delhi
2.	Das, Dr. Animesh	Professor, IIT, Kanpur
3.	Justo, Dr. C.E.G.	Emeritus Fellow, 334, 14th Main, 25th Cross, Banashankari 2nd Stage, Bangalore
4.	Momin, S.S.	Former Secretary, PWD Maharashtra, Mumbai
5.	Pandey, Dr. B.B.	Advisor, IIT Kharagpur, Kharagpur

Ex-Officio Members

1.	President, Indian Roads Congress	(Bhowmik, Sunil), Engineer-in-Chief, PWD (R&B), Govt. of Tripura
2.	Honorary Treasurer, Indian Roads Congress	(Das, S.N.), Director General (Road Development), & Special Secretary to Govt. of India, Ministry of Road Transport & Highways
3.	Secretary General, Indian Roads Congress	(Nahar, Sajjan Singh)

RECOMMENDED PRACTICE FOR RECYCLING OF BITUMINOUS PAVEMENTS

1 INTRODUCTION

1.1 The Flexible Pavement Committee (H-2) of IRC felt the need to formulate the document on Recycling of Bituminous Pavements. The draft "Recommended Practice for Recycling of Bituminous Pavements" prepared by Dr. Sunil Bose was discussed in a series of meetings of H-2. Committee.The H-2 Committee finalized the draft document in its meetings held on 3rd January, 2015 for placing it before the Highways Specifications & Standards Committee (HSS). The HSS approved the draft document in its meeting held on 12th January, 2015. The Council of IRC in its 204th meeting held at Bhubaneshwar on 19th January, 2015 approved the draft "Recommended Practice for Recycling of Bituminous Pavements" after taking on board the comments offered by the members.

The Composition of H-2 Committee is as given below:

Sinha, A.V.	--------	Convenor
Bose, Dr. Sunil	--------	Co-Convenor
Nirmal, S.K.	--------	Member Secretary

Members

Basu,Chandan	Mullick, Dr. Rajeev
Basu, S.B.	Pachauri, D.K.
Bhanwala, Col. R.S.	Pandey, Dr. B.B.
Bongirwar, P.L.	Pandey, R.K.
Das, Dr. Animesh	Reddy, Dr. K. Sudhakar
Duhsaka, Vanlal	Sharma, Arun Kumar
Jain, Dr. P.K.	Sharma, S.C.
Jain, Dr. S.S.	Singla, B.S.
Jain, N.S.	Sitaramanjaneyulu, K.
Jain, R.K.	Tyagi, B.R.
Jain, Rajesh Kumar	Rep. of DG (BR)
Krishna, Prabhat	Rep. of IOC Ltd.
Lal, Chaman	Rep. of NRRDA (Dr. I.K. Pateriya)

Corresponding Members

Bhattacharya, C.C.	Kandhal, Prof. Prithvi Singh
Jha, Bidur Kant	Kumar, Satander
Justo, Dr. C.E.G.	Seehra, Dr. S.S.
	Veeraragavan, Prof. A.

Ex-Officio Members

President, Indian Roads Congress	(Bhowmik, Sunil), Engineer-in-Chief, PWD (R&B), Govt. of Tripura
Honorary Treasurer, Indian Roads Congress	(Das, S.N.), Director General (Road Development), Ministry of Road Transport & Highways
Secretary General, Indian Roads Congress	Nahar, Sajjan Singh

1.2 Recycling of Pavement

Recycling of pavement is the process in which the existing pavement materials are reclaimed and re-used after reprocessing for either (a) resurfacing, or (b) repaving, or (c) reconstruction of pavement depending upon the condition of the existing pavement, the nature of the reclaimed materials, the method of reprocessing, and the treatment that the pavement requires. The justification for reclaiming the pavement materials, consisting mainly of aggregates and bituminous binders, is both environmental as well as economic. The aggregates existing in the pavement are part of natural resources drawn from the environment and should not be simply dumped at dump sites if a pavement fails or becomes unserviceable because it will cause damage to the environment, which will be further accentuated by extracting more virgin aggregates from the environment in replacement of the wasted materials. Economic justification comes from the utilization of the bitumen already existing in the pavement, which reduces the requirement of expensive virgin bitumen.

1.3 Reclaiming and Reprocessing of Pavement Materials

The reclaiming and reprocessing of pavement materials involve both design (how the pavement should be designed using reclaimed materials with the given properties) and technology (the methods to reclaim and reprocess, equipment, knowhow and quality) issues. Once both the issues are satisfactorily handled, there should be evidence of good performance of the recycled pavements in terms of strength, durability, and serviceability. If the three factors (design, technology and performance) combine, recycling of pavements is environmentally and economically better option for pavement repair, rehabilitation or reconstruction compared to one which uses fresh or virgin materials.

1.4 Variability in terms of Aggregate Gradation and Binder Content

The reclaimed materials usually have lot of variability in terms of aggregate gradation and binder content depending upon the location they come from (i.e. the project site and/or stockpiles), the layers they are drawn from (surfacing, bituminous base, or the granular bases), the method used for reclaiming (milling, ripping, breaking). This variability, which is required to be accounted for in designing a mix of uniform quality meeting the standards, is the designer's nightmare.

1.5 Overview of Reclamation and Recycling

The complete technology package requires consideration and provision of all the processes, viz. reclamation of the pavement materials (milling, ripping, breaking) handling the reclaimed materials (in-place or off site), the processing of the reclaimed materials (to achieve the design gradation including by adding fresh aggregates and to produce the new mix with the graded aggregates including by adding fresh binder) and construction. There are essentially two types of recycling technology, viz. (1) In-place and (2) In-plant, each having two variants, viz., (a) Cold and (b) Hot. Cold recycling technology has three options, viz., (i) Foam bitumen, (ii) Emulsion, (iii) Stabilization. Hot technology has two options depending upon the manner of reclamation by (i) hot process, or (ii) cold process. This is explained in the **Fig.** below.

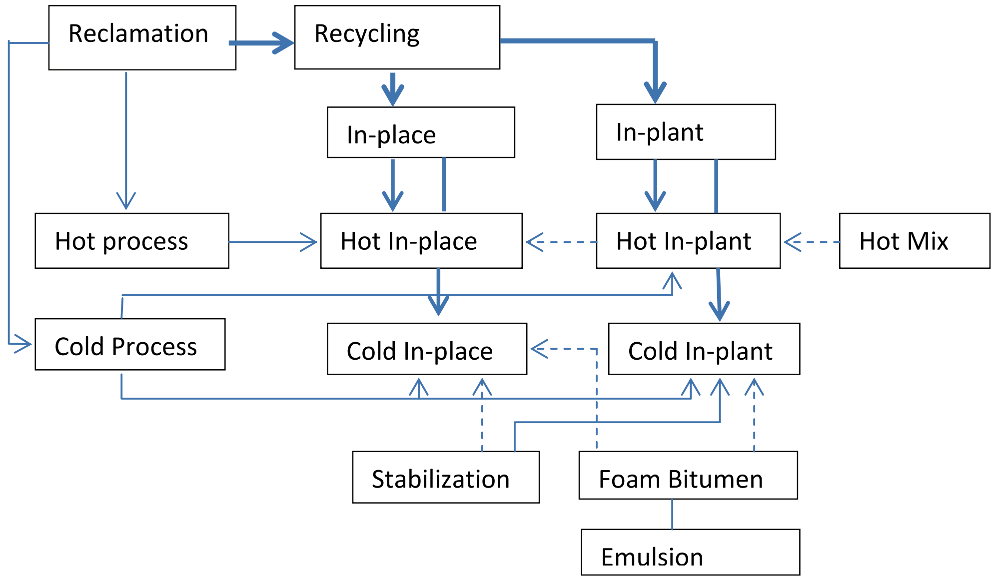


Fig. 1: Overview of Reclamation and Recycling

1.6 In-place Handling of Reclaimed Materials

The in-place handling of reclaimed materials is usually combined with mixing, laying and construction each in a close sequence. Off-site handling involves independent processes, such as re-crushing, segregation into different size fractions and stockpiling. Mixing (with or without heating and/or addition of fresh or virgin materials) is a separate off-site process, which is to be followed by transportation, laying and construction.

1.7 Performance of Recycled Pavements in India

As for performance of recycled pavements in India, the evidence is only anecdotal and no systematic documentation is available though it has been sporadically used in several projects in the country. The absence of Guidelines on the subject may be one of the reasons for lack of its widespread use. There are many documented evidences from abroad for good performance of the recycling technology subject to fulfilment of certain site specific and material specific requirements.

1.8 Different Aspects of Recycling

These Guidelines are framed to cover the following five aspects of recycling:

1. Reclamation (hot and cold processes)
2. Hot in-place recycling (HIR)
3. Cold in-place recycling (CIR)
4. Hot in-plant recycling (HIP)
5. Cold in-plant recycling (CIP)

1.9 Reclamation

Hot process reclamation is applicable only in HIR, while Cold Process reclamation can apply to all other recycling processes. In Hot Process reclamation, the existing pavement is heated by radiation and then milled or scarified while the hot bituminous surface is soft due to heating. The reclaimed material is invariably used in-place. In Cold Process reclamation, the pavement material is reclaimed by Cold Milling, breaking or ripping. In cold milling the pavement surface is milled to the required depth, the reclaimed material is discharged into a tipper truck and stockpiled at some designated site. The reclaimed materials are of the same size or lower compared to what had gone into in the original construction. Where ripping or breaking is done for reclamation, materials retrieved are in large chunks, which have to be crushed and then stockpiled. Before stockpiling the materials could be sieved and segregated and stockpiled into various size fractions. In any case, the dust produced by milling process should be separated. The milled material is stockpiled at some designated place after further crushing (if the reclamation process is by ripping or breaking the pavement instead of milling). Other reclamation processes, which are also cold processes, may involve ripping and pulverizing the non-bituminous bases/ sub-bases.

1.10 Hot in-place Recycling (HIR).

In HIR, a train of equipment is used with capabilities to perform different functions such as infrared heating of the pavement surface to soften it, milling the softened hot pavement surface, transferring the milled materials into Pug mill mixer of the Recycling equipment through a belt conveyor, adding fresh mix/binder/rejuvenator as per requirements of design into the pug mill, discharging the remixed materials into integrated paving screeds for paving the re-mixed output, rolling and compaction of the paved material. In HIR, 100 per cent of the reclaimed material is utilized. However, its limitation is that no more than 50 mm thick bituminous layer can be satisfactorily recycled (maximum 75 mm if softer binder was used in the original construction). If the pavement needs to be overlaid from structural consideration, a second layer of Hot mix overlay may have to be done on top of the recycled surface and in such situations (also called repaving), HIR has to be done in two layers (or multiple layers).

1.11 Hot in-plant Recycling (HIP)

This process involves production and laying of hot mix materials but not with virgin aggregates and binder but with a combination of reclaimed stockpiled aggregates already coated with binder and additional virgin aggregate and fresh binder to meet the requirements of the design. Usually, some rejuvenator is used to soften the old hardened binder in the reclaimed aggregates. Heating the reclaimed binder coated aggregates may release unacceptable fumes while feeding them cold directly into the pug mill may reduce the mixing temperature. The hot mix production process, therefore, has to be suitably modified. In all other respects, hot in-plant recycling is just like normal hot mix construction. Not more than 50% of the reclaimed material is used, though a widely accepted percentage is only 30) and the thickness in which it can be laid is typically 100 mm.

1.12 Cold in-place Recycling (CIR)

In this process, milling and mixing are simultaneous processes accomplished by a single equipment or a train of equipment capable of milling and conveying the milled material to be fed to a pug mill, with parallel supply line for feeding fresh aggregates also, and separate feeding lines to the pug mill for bitumen emulsion, and rejuvenator. Where foam bitumen is to be used, there has to be separate feeding line for hot bitumen and water to produce the foam bitumen and then feed into the pug mill. The mixed material is discharged into the paver hopper closely following the recycling equipment or train of equipment, then paved and compacted. This type of recycling is considered suitable for depth upto 150 mm and the use of reclaimed material is also of the same order (typically 30 to 50%) as in HIP.

Another variant of cold in-place recycling is Full Depth Reclamation, where the thickness of pavement to be recycled is greater than typically 150 mm. The pavement is ripped, the material pulverized and stabilized with lime, cement or cementitious materials and compacted into base layer of the required strength.

1.13 Cold in-plant Recycling (CIP)

The process involves production of the mix in a plant using either emulsion or foam bitumen and laying and compaction in the usual manner. A rejuvenator is to be added in the mixing process to soften the hard binder in the reclaimed material. The application range in terms of depth of recycling and use of reclaimed materials is typically the same as for cold in-place recycling.

2. SCOPE

The document covers the following in respect of all types of reclamation and recycling

(1) Investigations required for making informed decision on recycling

(2) Suggestions regarding appropriate methods of recycling under different circumstances

(3) The details of each type of reclamation and recycling (in separate Parts of this document)

(4) Considerations in design of each type of recycling treatment

(5) The Technology and quality assurance issues involved in the process of recycling

(6) The documentation required in any recycling project.

3. INVESTIGATIONS

The following types of investigations on the existing pavement are required

(1) Pavement condition

(2) Pavement composition and history

(3) Structural evaluation

(4) Existing Pavement Material properties

3.1 Pavement Condition

Pavement condition will be investigated for identifying all the defects as listed out in IRC 82: 2014. In addition, cores of 150 mm diameter should be taken along the width of the carriageway on the severely distressed section at 0.75 m, 3.85 m and 6.95 m from the inside edge of the shoulder. Cores should be taken in a staggered manner along the length of the pavement at locations such that one core sample every 300 m length of the road is available. Depth of the core should be at least equal to the depth of bituminous thickness. In case the crack is observed over the entire depth of the bituminous layer, the investigation through core or test pits should be carried out through the granular/ bound bases of the pavement as well to ascertain if full depth reclamation would be needed.

The cores should be referenced and photographed, and the observation recorded in terms of crack depth, crack width and other visual observations on the core such as deficient or uneven bitumen coating, signs of shear (diagonal or transverse cracking) or any other observation.

The cores should be used for testing the material properties of the existing pavements.

Pavement roughness should be measured by running the Bump Integrator and stretch-wise data should be recorded.

Skid resistance measurements should also preferably be recorded.

3.2 Pavement Composition and History

Composition of the pavement including the type of pavement layers, the layer thicknesses, year of construction, history of interventions (resurfacing/renewal/reconstruction) and time of such intervention, the aggregate source (if possible), job mix formula, binder content and the type of binder should be gathered from records and documented.

3.3 Structural Evaluation

Structural evaluation of pavement should be carried out with Falling Weight Deflectometer in accordance with IRC 115 (2014) and the residual life of the pavement and the overlay requirements for various time horizons (5, 10, 15 years) should be determined.

3.4 Existing Pavement Material Properties

The material of core samples should be used for determining the properties of aggregate and binder in the existing pavement. Most relevant properties to be tested are

(i) Bulk density of the existing mix

(ii) Aggregate gradation

(iii) Binder content

(iv) Viscosity of the binder in the core samples

4. GENERAL CRITERIA FOR INVESTIGATION TO DETERMINE RECYCLING OPTION

The results of the investigation of the existing pavements should be analysed in terms of

(i) Serviceability of the pavement

(ii) The extent of surface defects

(iii) Structural strength

4.1 Serviceability of Pavement

Serviceability of the pavement is usually a subjective assessment of the users' needs in terms of riding quality and comfort. One would not like to drive on a cracked, ravelled bumpy road. To what extent the surface deterioration of pavement can be tolerated is the decision which Road Authorities have to take within the constraints of their resources. When the serviceability of the pavement deteriorates beyond a point, one of the options available is recycling apart from many other maintenance and repair measures like sealing, patching, micro-surfacing, surface renewal, etc. In order to objectively assess the acceptable serviceability level beyond which recycling should be considered an option, these Guidelines recommend that where (a) the distresses can be categorised as "High Severity" distress as defined in IRC 82:2014, or (b) road roughness exceeds 3000 mm per km, or (c) rut depth exceeds 20 mm, should be considered for recycling. All surface renewals could be a candidate for recycling.

4.2 The Extent of Surface Defects

It would be necessary to know whether the defects appearing on the surface are confined to the surfacing course itself or have progressed in the lower layers of pavement as well, such as bituminous bases or granular or bound bases/sub bases. This would be determined by examining and analysing the cores taken during investigation. Pavement should be recycled to the depth of distress. If the distress extends into the bituminous bases, this is a clear indication of failure of the base as well. A strengthening overlay would be called for and recycling combined with overlay would be a solution. If the distress extends into granular or bound bases, the bituminous pavement material should be reclaimed and the base pulverized, stabilized and relayed while the bituminous layers could be built using reclaimed and fresh materials.

4.3 Structural Strength

If the structural evaluation of the pavement reveals that the residual life of the pavement is sufficient to take the wheel load repetitions for the next five years, the pavement should be considered as adequate for the time being and recycling of only surface layers should be considered if the surface condition warrants it. Otherwise, recycling should be combined with overlaying.

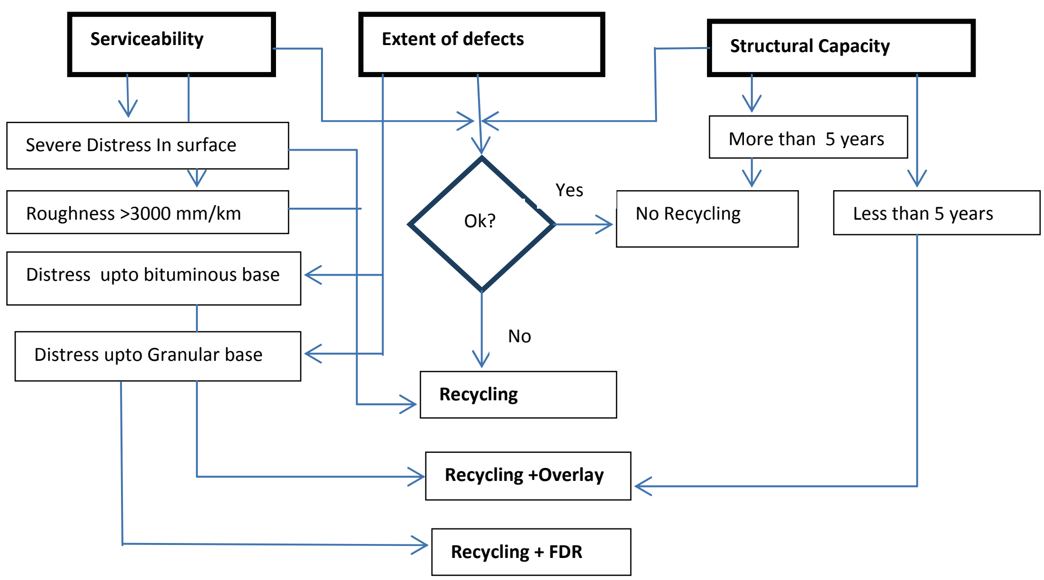


Fig. 2: General Criteria for recycling overlay and Full Depth Reclamation

The **Fig.** 2 explains the general criteria for recycling either alone or in combination with overlay or full depth reclamation.

4.4 Recycling Options

The Table below suggests which of the five recycling options would be suitable in different situations. Where depth of recycling is limited, in-place methods (both Hot and Cold) would be suitable because these utilize the reclaimed materials to the maximum extent. There is not much merit in using in-plant methods in such cases as only 30 per cent of the reclaimed materials can be used. When recycling in deeper depth is required, in-plant methods are the only options. As far as choice between hot or cold processes, for both in-plant and in-place methods, is concerned, the choice would depend upon economic, environmental and the capability (of producing the mix meeting the design requirements) factors.

Defects/ Deficiencies	Preferable Recycling options				
		HIR	HIP	CIR	CIP
Serviceability of pavement and extent of defects	High Severity defects no structural deficiencies	Y	N	Y	N
	High severity defects extending up to bituminous bases	N	Y	N	Y
	High severity defects extending up to granular bases	-	-	Y*	-
Structural strength	Only resurfacing	Y	N	Y	N
	Resurfacing with overlay	N	Y	N	Y

HIR: Hot In-place recycling HIP: Hot In-plant recycling CIR: Cold In-place recycling CIP: Cold In-plant recycling

*Full Depth Recycling

4.5 Limitations as to Depth of Recycling

The following are the maximum recommended depths of recycling

HIR: 50 mm

HIP: 100 mm

CIR: 75 mm

CIP: 100 mm

In case the thickness required as per design is more, the balance thickness should be made up by hot mix materials, the recycled layer acting as levelling course.

4.6 Limitations as to Proportion of Reclaimed Materials in the Recycled Mixes

In HIR or CIR 100 per cent of the reclaimed materials can be used. In HIP and CIP not more than 30 per cent of the reclaimed material should be used.

4.7 Some Illustrations on Selecting a Recycling Option

Photo 1 illustrates a ravelled surface. Ravelling must have been preceded by cracking. If the cracks are only in the surface layer, HIR is a suitable recycling option. The ravelled portion should be applied with thin coat of emulsion to restore the lost bitumen before HIR mix and prevent dust contamination of the HIR mix.

Photo 2 is a typical example of fatty surface giving poor serviceability in terms of riding quality and skid resistance. HIR should be a suitable option

Photo 3 shows a polished aggregate surface. This is not suitable for any type of recycling because the polished surfaces would not allow bitumen to stick on the aggregates. Chip seal, surface dressing, Micro surfacing would be a better option to increase friction. With or without overlaying

Photo 4 shows a corrugated surface giving very poor serviceability. If the corrugations are not present in the base layer (which can be ascertained by digging test pits across the pavement), it could be due to faulty mix design using softer binder and HIR or CIR could be an option. If the top of the granular base also shows corrugation, it would be indicative of subgrade failure of the pavement and Full Depth Recycling would be an appropriate solution

Photo 5 shows rutting and slippage, which could be due to faulty mix design and use of softer binder. This type of surface could be treated with HIR

Photo 6 shows longitudinal and diagonal cracks. Longitudinal cracks may be due to faulty construction (lack of bond at cold joints) while the diagonal cracks are indicative of shear failure of the mix. Subject to further investigations proving otherwise, HIR or CIR could be a suitable option.

Photo 7 shows alligator cracks on the surface. Too much dust contamination and loss of binder, HIR would not be a suitable solution and HIP or CIP could be a better option provided cracks have not progressed deeper than the surface course.

5. DESIGN CONSIDERATIONS

5.1 Managing the Variability in Properties of Reclaimed Materials to make them Compatible with Fresh Materials

The objective of design of recycled mixes is that they should meet the same requirements as expected of mixes with virgin materials and their performance should be equal to or better than virgin mixes. The in-situ bituminous materials, which are reclaimed for use in recycling, have the following characteristics:

(1) The bitumen is aged, oxidized and hardened and hence the viscosity of the reclaimed binder is much higher than the fresh binder of the same grade as used in the original construction

(2) The aggregates get crushed during the process of reclamation, particularly when the reclamation is by the process of cold milling, and hence their grading changes from those of the original mix.

(3) In case the reclaimed bituminous material is stockpiled, drawing up materials from the stock pile may have variability with regard to physical properties and aggregate gradation and source, bitumen grading and source.

The main design consideration is to manage these variabilities and make the reclaimed and fresh materials compatible.

5.2 Method of Improvement of Binder in the Reclaimed Material

Hardened bitumen in the reclaimed materials has to be made softer. This can be done mainly in two ways,

(i) By adding rejuvenating agents to bring the combined viscosity of the binder to acceptable level. Rejuvenating agents are commercially available patented products. The manufacturers of the materials should be required to demonstrate the effectiveness of their application and assure against any harmful ingredients therein. If the rejuvenating agents do not penetrate into the hardened bitumen properly, they would lubricate the mix and would be counter-productive.

(ii) By adding softer grade bitumen to mix with the hard bitumen extracted from the reclaimed mix to soften it to the acceptable level. Extraction of old bitumen should be done by Abson Recovery Method (ASTM D 1856-95 A) What is the acceptable level of softening can be decided in the following ways:

(a) By the combined Viscosity of the mixed binder: This can be done by a standard blending chart. One such chart developed by FHWA is shown in the **Fig.** 3 below.

(b) By the combined Softening point: The softening points of the old and new binder combined in various percentages are determined to arrive at the target softening point.

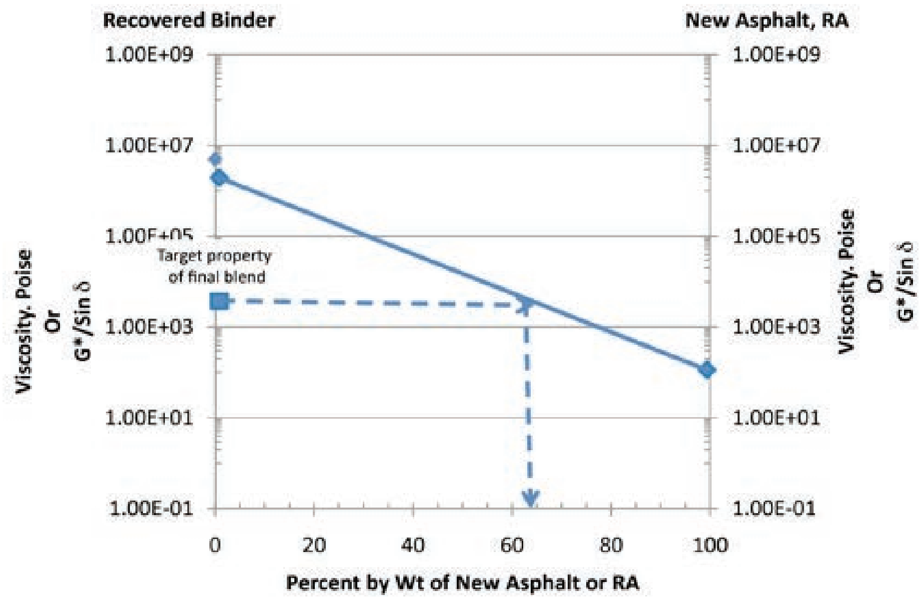


Fig 3. Blending Chart (Source NCHRP Synthesis Report 421)

5.3 Rectification of Aggregate Grading

Aggregate grading of the reclaimed material has to be determined and the missing fractions have to be added to arrive at the appropriate grading as per IRC:111 (for Hot mix application) and IRC:SP:100 (for cold mix application).

5.4 Mix Design Considerations

All other design considerations such as Stability, V_a, VMA, VFA, etc. would be the same as those applicable for normal bituminous mixes prescribed in the relevant guidelines, codes or specifications.

Photo 8. Milling in Operation

5.5 Mix Design Procedure using Foam Bitumen

In recycling where recycling agent is foam bitumen, the design procedure is given in **Annex 1**.

6. RECLAMATION

Reclamation normally involves three processes viz milling, demolition and full depth reclamation. In situations where recycling is to be done in place (HIR, CIR), reclamation and recycling are combined processes.

6.1 Milling

Milling is the control removal of an existing pavement to a desired depth, using specially designed equipment having replaceable tungsten carbide cutting teeth mounted on a rotor drum driven by the power supplied by the milling machine. It is the most common way of reclaiming the bituminous pavement material. It is mostly used following a cold process, and hence commonly known as cold milling, though milling is done following hot process also in HIR. This section deals with cold milling only.

Important aspects to be considered in cold milling are the depth of milling, appropriate milling tools to govern the size of milled material, control of dust, collection and transportation of milled material, and stockpiling. Milling processes should be closely examined to make sure that the milled material is not contaminated with soil, base material, paving geotextiles, or other debris. This is particularly important for deep mills or milling on shoulders or widened roadways. Milled materials that become contaminated should be used only as shoulder material and should be stockpiled separately. A recommended maximum limit of 1% deleterious material should be used to evaluate reclaimed bituminous materials. The milled surface should also be inspected for “scabbing,” where thin, weakly bonded layers are left in place. If this is observed, the milling depth should be adjusted to remove the scab layer because, if allowed to remain in place, the performance of overlay will be poor.

The milled surface should be inspected for uniform texture. A non-uniform texture resulting from worn or broken tips on the milling drum can cause problems with compaction of thin overlays. It may also cause an unsafe surface for motorcycles if the milled surface remains open to traffic. In such cases, it should be ensured that riding surface is safe for motorcycles, by having a reasonable limit on peak to valley distance of the milled surface.The finished milled surface should be within 6-8 mm of a true profile grade both in transverse and longitudinal directions, when measured with a 3-m long straightedge (Photo 9).

If the milled surface is to be the final surface of the pavement, it should have either continuous or intermittent striations or any other pre-approved pattern which will provide an acceptable level of skid resistance. If pavement is to be constructed over the milled surface, it shall have a texture which will provide good bonding.

Photo 9: Good surface after milling

Milling machines transfers maximum energy on to milling drum in removing pavement layers by impacting the pavement with milling teeth mounted on a drum rotating at about 200 rpm. The impacts break up the pavement by ripping through the mastic and aggregate particles. Crushing of aggregate particles causes the gradation of the millings to be finer than the gradation of the pavement layers in place. The final gradation required of the reclaimed bituminous materials (RBM) by milling can be obtained by controlling depth of milling cut, and speed of machine .Also Gradation bar on milling machine helps to control the cut size.

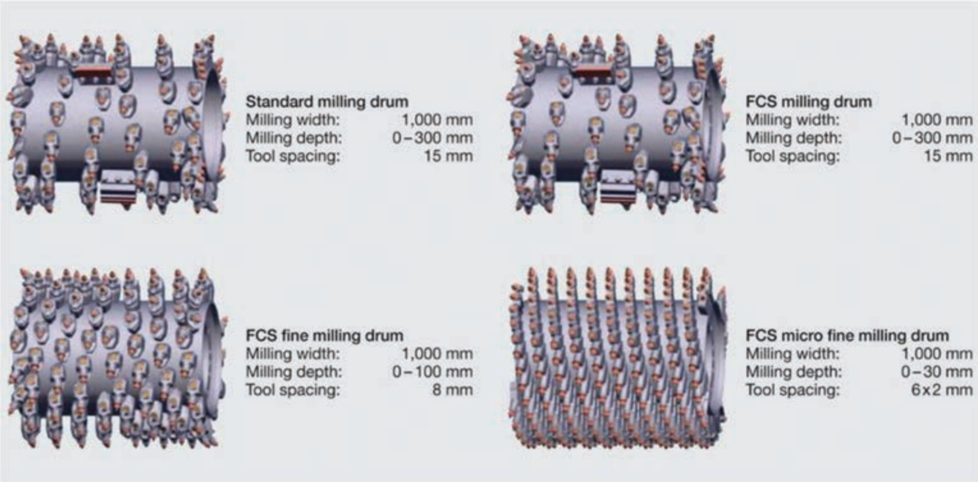


Photo 10. Different types of milling teeth on rotar

6.2 Pavement Demolition

RBM may also be obtained from demolition of an existing pavement using a bulldozer or backhoe. This process is typically limited to small areas of pavement. It is slow and results in large chunks of pavement that may be more challenging to process into a useable recycled material. When pavement rubble is contaminated with underlying layers and soil, it is better for this material to be crushed and used as a shoulder or base material than used in bituminous mixture.

The limitation of backhoe loader or excavator is that there is a possibility of damage to the layer below the bituminous layer besides the retrieved materials, being in the form of lumps, cannot be used without re-crushing. While disposal of unusable material lumps is environmentally damaging, making them usable by re-crushing is also fraught with some problems as the lumps instead of breaking may tend to become stickier due to presence of bitumen, especially in hot weather. Thus, it is not easy to get a proper grading out of such materials even after re-crushing.

6.3 Full Depth Reclamation (FDR)

In Full depth reclamation (FDR) all the reclaimed materials of the pavement, with or without fresh materials, is stabilized in-situ with suitable stabilizers to produce the base course of the pavement to be overlaid by bituminous course(s). If economically feasible, it is preferable to reclaim the bituminous layer and other granular or bound layers separately to retrieve as much useful and high value bituminous materials as possible. In the latter situation, reclamation and recycling would be in two stages.

6.4 Management of Reclaimed Material Stockpile

Reclaimed material should be stockpiled and managed as per the details given in Appendix III to Annex 1.

7.0 COLD RECYCLING

Cold recycling involves reuse of the existing pavement materials without the application of heat. The recycling agent in cold recycling can be emulsion, foam bitumen, rejuvenator, and cementitious materials, either alone or in combination. Cold recycling offers three options,viz.,Cold In-place Recycling (CIR), Cold In-Plant (CIP) and Full Depth Reclamation (FDR).

7.1 Cold in Place Recycling (CIR)

A CIR plant or Recycler should be equipped with

(a) Cold milling equipment to mill the existing pavement,

(b) A system to carry the milled materials to vibrating screens with a separate line for fresh aggregates

(c) A system for proportioning and weigh batching of different size fractions

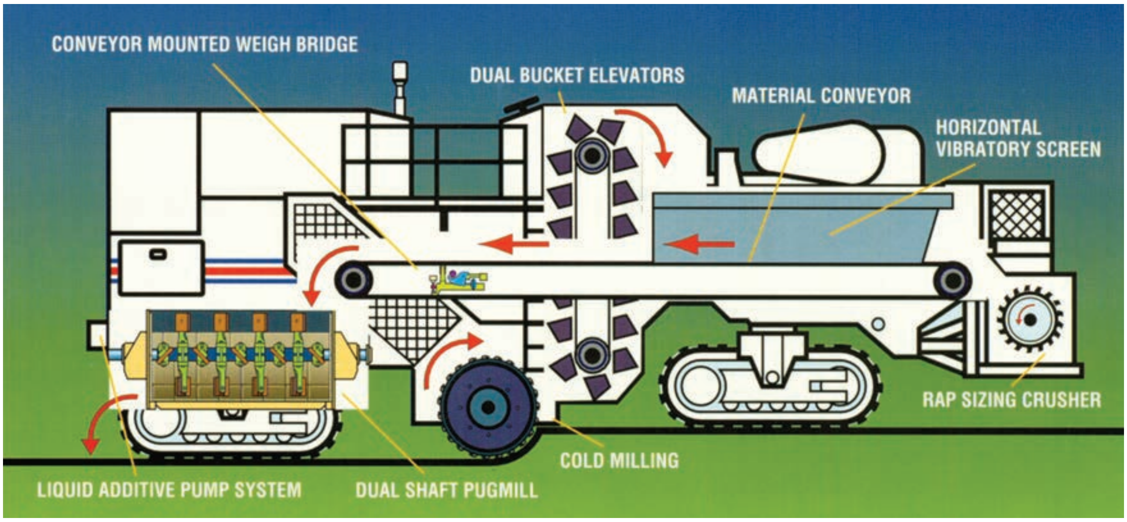
(d) A Pug mill for mixing with separate material feed lines for aggregates, binder and rejuvenators

(e) Vibrating screeds for tamping and profiling the mixed materials discharged from Pug mill

(f) Compaction equipment for compacting the mix

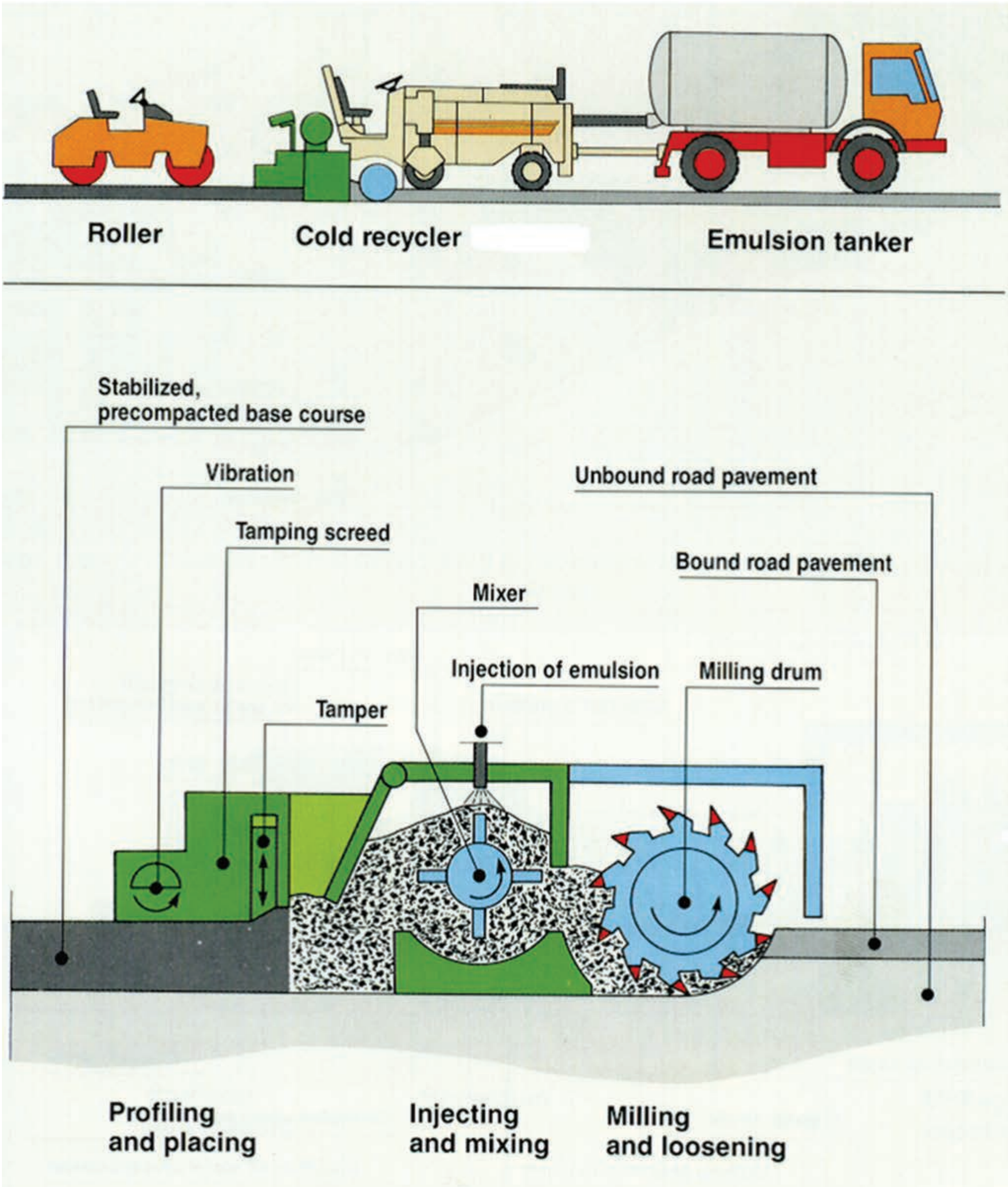
(g) Appropriate arrangements for controlling dust and noise pollution

The machines should have electronic controls for inputs, processes and outputs. A single machine can have all these features or there can be a train of equipment for performing different functions. Schematic diagrams for the cold in-place recycling plants are presented in Photos 11 to 14 below.



(Source: FHWA cold in place recycling)

Photo 11: Schematic arrangement for CIR with emulsion



(Source: FHWA cold in place recycling)

Photo 12: Another Schematic arrangement for CIR with emulsion

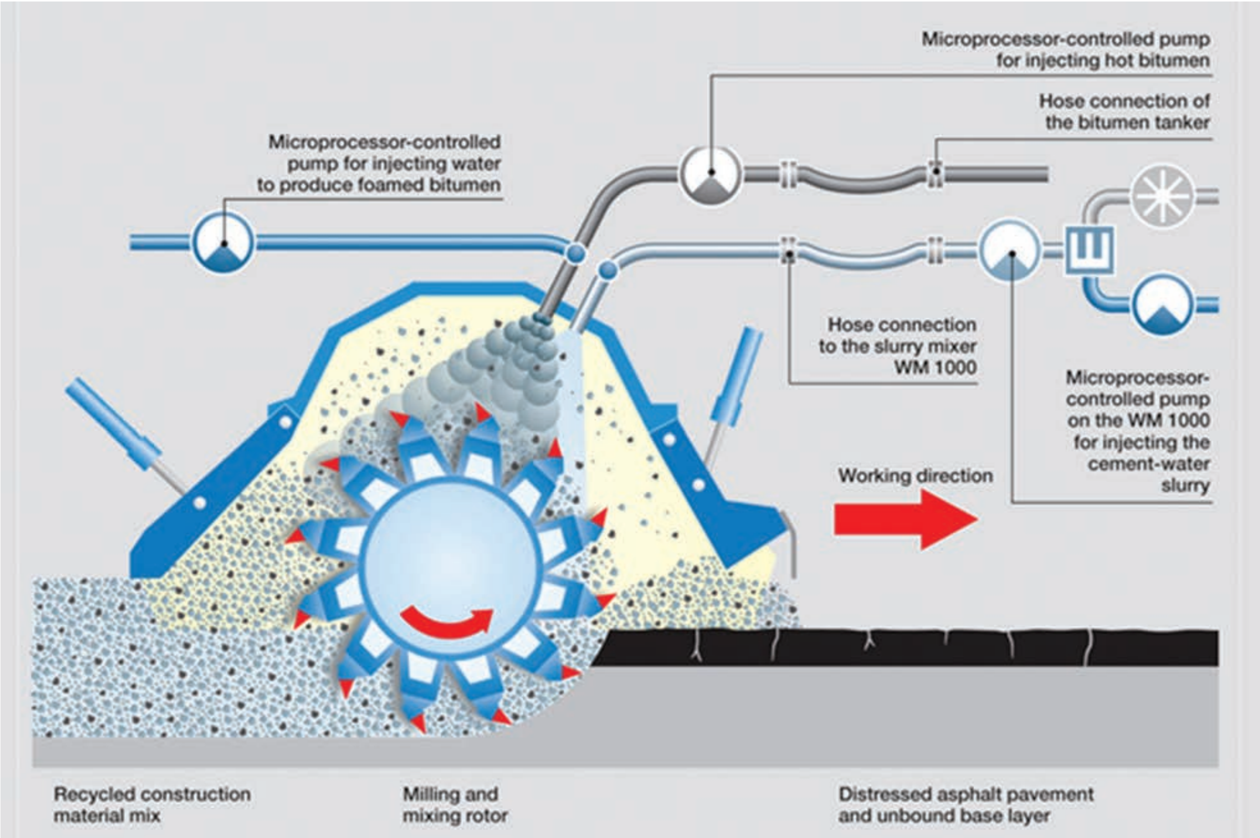


Photo 13. Schematic arrangement for CIR machine using foam bitumen

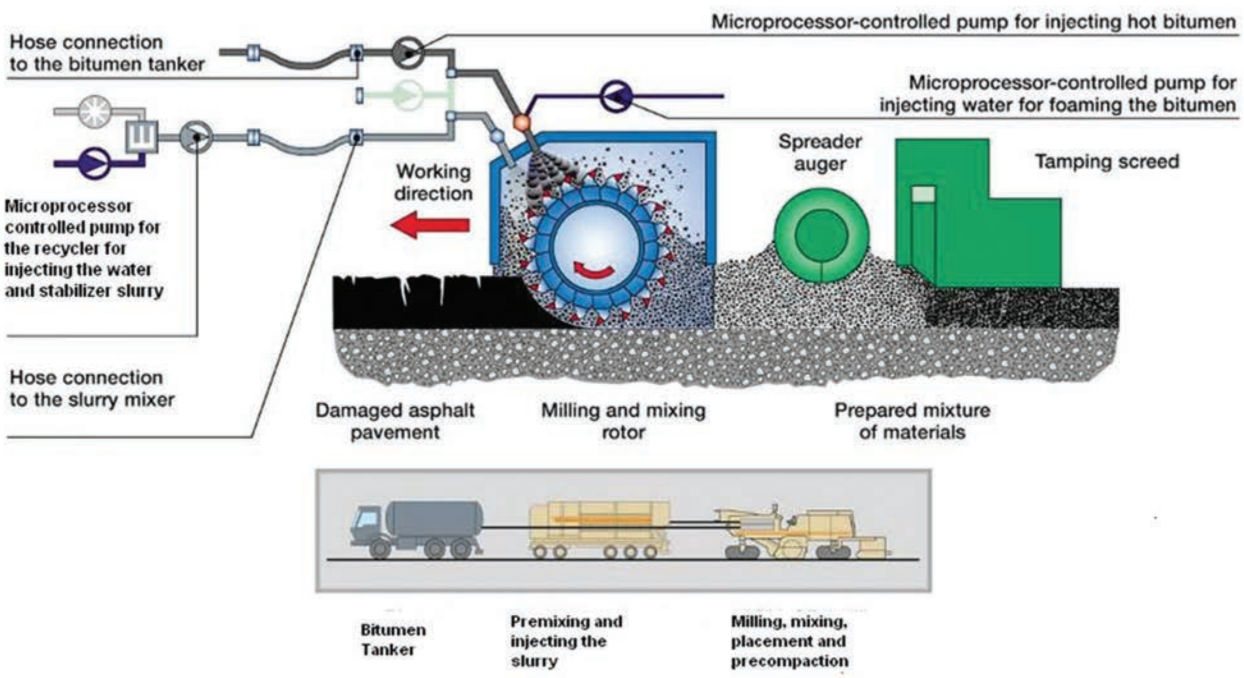


Photo 14 : Another schematic arrangement for CIR with Foam Bitumen

7.2 Cold in Plant Recycling (CIP)

In the cold in-plant recycling, the RBM is transported to a mobile cold mixing plant located in the vicinity of the job site. Measured quantities of RBM and fresh aggregates are cold fed into a twin shaft pug mill and metred quantities of binder, either in the form of bitumen emulsion or foam bitumen, is injected. All the ingredients are mixed and blended for a certain duration to produce a homogeneous mix, which is transported to the work site, paved and compacted. The requirements of CIP, therefore, involve proper control on material feed and mixing process, including the mixing time.

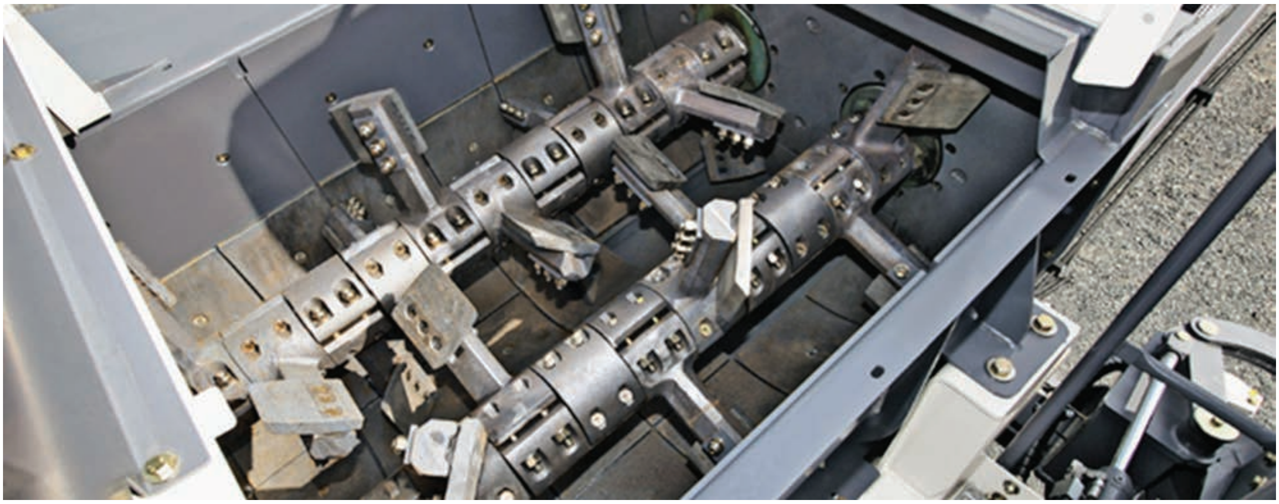


Photo 14: View of a twin shaft pug mill of a cold mixing unit

Precise control on the mixing time is important because over-mixing can cause premature breaking of emulsified bitumen; under-mixing may result in insufficient coating of aggregates. Similarly, the rate of injection of hot bitumen and water to produce the foam bitumen should be so regulated that the bitumen foam uniformly coats the aggregates.The CIP plant should have all the features and controls as described in para 7.1 above. A view of the twin-shaft pug mill is given in Photo 14.

8. HOT IN PLANT RECYCLING (HIP)

Hot in-plant recycling involves the usual Hot mix production process with three main differences, viz (i) instead of all fresh aggregates and bitumen in the usual Hot Mix production, HIP uses RBM to the extent of 30 %, (ii) rejuvenators are required to soften the oxidized binder in RBM, and (iii) unlike normal hot mix production process the RBM cannot be directly heated as it would generate fumes. These factors have to be adequately managed by brining modifications in the Hot Mix Plants, especially the material feed system, and changes in the production process. Subject to these modification and changes, the Plant can be a Continuous or Batch type.

9. HOT IN PLACE RECYCLING (HIR)

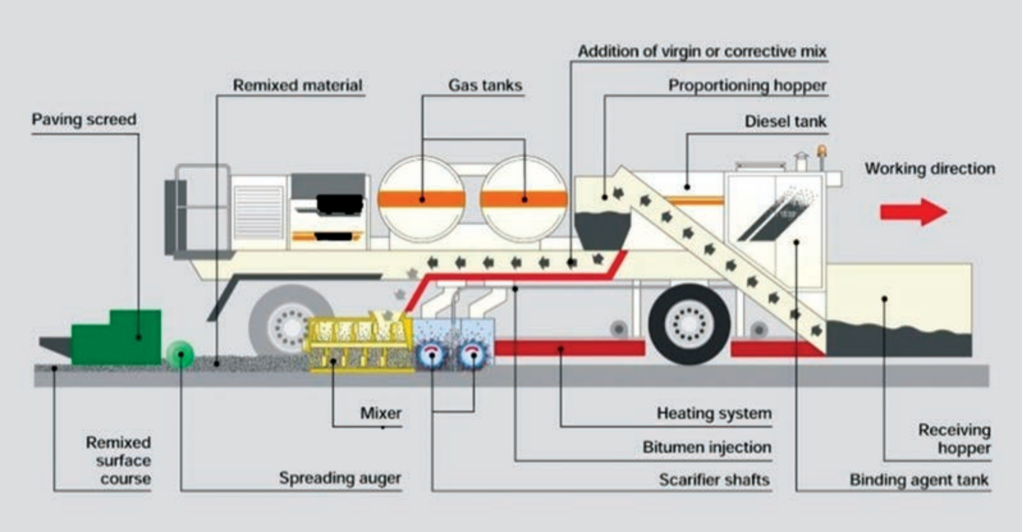


Photo 15. Schematic arrangement for an HIR plant

An HIR Plant should have the following features and controls:

(a) An infrared radiation heating system, which can heat the existing pavement surface uniformly

(b) A scarifier to rip the existing bituminous surface to the required depth

(c) A collecting hopper to collect the scarified hot bituminous mix from the scarified pavement

(d) Feed lines for controlled addition of additional binder and rejuvenator to the scarified mix in the collecting hopper

(e) A conveyor system to carry the scarified mix, additional binder and rejuvenator to the proportioning hopper

(f) A proportioning hopper for controlled discharge of the mix to a conveying system leading to the mixing unit

(g) A feed system for controlled addition of virgin mix to be added to the old mix

(h) A conveyor system to carry the proportioned old and new mixes to the mixing unit

(i) A mixing unit to mix the old and new mixes

(j) A discharge system for discharging the mix

(k) A spreading augur to evenly spread the mix to the surface to be overlaid

(l) A paving screed with provision for tamping and vibration

(m) A compaction unit to compact the mix after paving

In Hot In-place recycling (HIR) the existing pavement is heated and softened, and then scarified/milled to a specified depth. The critical issues involved in HIR plants and processes are the heating of the pavement surface, scarification, collecting and conveying the RBM to the mixer, addition of rejuvenators and fresh mixes into the mixer, proper mixing of all the ingredients, laying and paving of the mat and compaction. The HIR plants, therefore, should have all these facilities in one plant or should have a train of equipment performing different functions in a synchronized manner. Heating, material feed, mixing and laying are the processes to be strictly controlled. For example, heating of the surface has to be uniform and for that the number of preheating units is not as important as the length of the heating areas/hoods on each preheater. Similarly, the rejuvenator doses have to be metered and controlled. Where fresh mixes are added, its input quantities have to be controlled. HIR can be a single pass or multiple pass process. In single pass operation, the scarified in-place material is compacted and that is the end of the process. In multiple pass operation, the compacted mix is overlaid by fresh mix. The depth of treatment varies between 20 to 50 mm and the temperature of the mix in the range of 110-150 deg C. Schematic arrangement for an HIR plant is given in Photo 15.

10. FULL DEPTH RECLAMATION (FDR)

Full Depth Reclamation (FDR) is basically a cold mix recycling process in which different types of additives such as foam bitumen, bituminous emulsions and chemical agents such as cement, fly ash, and lime, including commercially available cementitious stabilizers are added, mostly in-situ, and compacted to obtain an improved base. The four main steps in this process are pulverization, introduction of additive, mixing, compaction, and application of a surface or a wearing course. If the in-place material is not sufficient to provide the desired depth of the treated base, new materials may be imported and included in the processing. New aggregates can also be added to the in-place material to obtain a particular gradation of material.

- Pulverization should produce minus 40 mm size and should conform to the gradation as per IRC 37 for the purpose of stabilization.
- The Sand Equivalent (SE) value from the combined materials should not be less than 30%.
- Emulsion content, in case of bitumen stabilization should be such that indirect tensile strength in dry and wet conditions (100 mm specimen) is more than 225 KPa and 100 KPa respectively and voids in the range of 6–8%.
- Resilient modulus for all stabilized material should be in accordance with the IRC 37.
- Stabilization should be done in-situ with suitable plants and equipment. Where it is not possible to have these plants and equipment (for smaller jobs), WMM plant can be used for mixing.

This method of recycling is normally performed to a depth of 100 mm to 300 mm.The train of equipment consists of recycling machine hooked to a water tanker and steel drum roller with pad foot shell. The advantages of full depth reclamation are that most pavement distresses are treated, hauling costs are minimized, significant structural improvements can be made (especially in base), material disposal problems are eliminated, and ride quality is improved.

Photo 16. Milling the Bitumen Crust for FDR

Photo 17

Photo 18

Photo 19

Photo 20.

Photo 17-20 Stabilizing the base layers after Milling for FDR

11. LIST OF RECYCLING PROJECTS IN INDIA

The lists of some of the projects executed in India is at **Annex 2**.

12. IMPORTANT PARAMETERS TO ENSURE SUCCESS OF RECYCLING.

The success of recycling projects would depend upon appropriate choice of the recycling option, proper design, and selection of recycling agents, capability of plants and equipment, and logistics of operation.

i. Choice of a suitable option: Recycling option has to be selected on the basis of strengths and weaknesses of each option. In-place option has a depth limitation of 50 mm (HIR) and 75 mm (CIR). In plant option is suitable for larger depths and multi- layer construction combining an overlay.

ii. Design: To arrive at a design and Job Mix Formula involves much more effort and many more tests and trials with different combination of RBM, fresh aggregates and recycling agents than are required in conventional design of hot or cold mixes because the design is highly sensitive to the properties of the RBM.

iii. **Plant capabilities:** The controlled addition of the JMF ingredients for preparing the mix is extremely important and the user of this technology should look for these capabilities in the plants and equipment proposed to be deployed on the project. Mechanical or hydraulic controls should be insisted upon as appropriate for components feeding the ingredients and the latter should be weighed or metered using electronic sensors. The processing parameters like heating, mixing, mixing time should have electronic controls, whereby these can be preset, and auto shut off facility when the set limit is exceeded (e.g. thermostatically controlled heat transfer with electronic heat sensors). The plants and equipment should have capabilities to ensure synchronized operation of various components, all controlled from a central control panel.

iv. **Logistics of operation:** This is another important consideration in the use of this technology, particularly in the in-place processes where the process has to be carried out at the site without disturbing the traffic. Each activity from production to completion should have a logistic planning so that the production process runs smoothly and after the mix is produced; there is arrangement for paving and compacting the mix within appropriate time limit.

While deciding upon Recycling treatment under any project, each of these aspects need detailed consideration. A complete technology package should be asked to be offered by the agency undertaking the work.

Annex 1

GUIDELINES FOR MIX DESIGN, CONSTRUCTION AND QUALITY CONTROL FOR COLD IN PLANT AND INSITU RECYCLING USING FOAM BITUMEN MIXES

Annex 1 deals with various aspects of Recycling using foam bitumen. Appendix I to this Annex deals with design procedure, Appendix II with the Quality Assurance issues and Appendix III with how the Reclaimed Bituminous materials (RBM) should be managed.

Bitumen for Foaming:

Bitumen used for foamed bitumen stabilisation shall be penetration grade bitumen complying with Indian Standard Specification for “Paving Bitumen IS: 73”. The grade of penetration bitumen shall be between 60 and 150. It is desirable to specify the grade in the contract. The bitumen should be free of any anti-foaming agent and should have the following minimum foaming characteristics (refer Appendix I):

Expansion ratio:	**8-10 times**
Half-life:	**6 seconds**

The temperature of the bitumen at the time of foaming should be between 160°C and 190°C.

Water: Water used in the cold in-situ recycling process should be potable, clean and free of harmful matter.

Mixture Design

The mixture design procedure to be followed for foamed bitumen stabilised material is described under Appendix I to this Annex. Separate mixture designs shall be carried out for each different material combination that will be encountered in the construction. The results for each mixture design shall include:

- the temperature range at which the bitumen is to be foamed;
- the amount of water to be injected into the bitumen to achieve the required foaming characteristics;
- details for any blending with imported material requirements (material specification and blend ratio in volumetric terms);
- the application rates for foamed bitumen and filler as a percentage (by mass) of the material being treated;
- target strengths in terms of Indirect Tensile Strength (ITS) tests carried out on specimens prepared for Quality Assurance testing (as described in AnnexureII).

Tests specific to foamed bitumen stabilised materials are included in Annexure II. The following additional tolerances shall apply to the foamed bitumen stabilised layer:

i) **Consumption of stabilising agents and filler:**

Application rates specified in the relevant mixture design ± 0.2%

ii) **Strength of briquette or core specimens**

Indirect Tensile Strength: ITS_{DRY} value > 90% of the ITS_{DRY} value specified in the relevant mixture design

Tensile Strength Retained: TSR > 80% of the TSR value specified in the relevant mixture design.

iii) **Density:** Densities shall be measured for the full layer thickness and related to the maximum dry density determined as per IS 2720 (Part 8) for the relevant blend of stabilised material. The average density of a "Batch" shall be related to the thickness of the layer and the underlying support conditions, as detailed in Table 1.

Table 1: Density Requirements (Relative to the Maximum Dry Density for the Material Determined in Accordance with is: 2720 (Part 8))

Layer Thickness (mm)	Support Conditions Beneath New Compacted Layer		
	Weak (Thin Granular Structure / Poor Subgrade)	Moderate (Thick Granular Structure / Average Subgrade)	Good (Bound Materials / Good Subgrade)
< 150	98	100	102
150 to 200	97	99	102
200 to 250	96	98	100
250 to 300	95	97	100
> 300	93	95	98

No individual density test result shall be less than that specified minus 2%.

Opening to Traffic

All traffic shall be kept off the completed layer of foamed bitumen stabilised material until the surface has dried out. Whilst under traffic, the surface of the completed shall be kept continuously damp during daylight hours by frequent light watering for at least three days. Thereafter and until the surfacing is applied, the surface shall be continuously monitored for signs of deterioration caused by the action of traffic. Where ravelling is detected, the surfacing shall be applied without delay, provided the moisture content of the stabilised layer has reduced to the required level. Alternatively, a temporary seal consisting of diluted emulsion (as described in Section 510) shall be applied to protect the surface until the Bituminous is paved.

Delay before Covering

Application of the surfacing (surface dressing or Bituminous) or subsequent layer shall be delayed until the moisture content of the upper 10 cm horizon of the foamed bitumen stabilised layer, checked in accordance with IS 2720 (Part 2), has reduced to below 50% of the Optimum Moisture Content (OMC) determined as per IS 2720 (Part 8) for the relevant blend of stabilised material.

Dealing with Unforeseen Circumstances

Excess moisture: Where the in-situ moisture content of the material in the recycling horizon, checked in accordance with IS 2720 (Part 2), is in excess of the Optimum Moisture Content (OMC) determined as per IS 2720 (Part 8), the existing pavement shall be pulverised without any additives to a depth 5 cm above the required recycling depth (i.e. recycling thickness minus 5 cm). The pulverised material shall be left open to the atmosphere to dry. This drying process can be accelerated by frequently cross-blading the pulverised material with a motor grader, or with a plough.

After drying sufficiently (to below 75% of the OMC), the shape of the original surface shall be reinstated by grader and compacted to achieve a nominal 95% of the maximum dry density determined as per IS 2720 (Part 8). Thereafter, the recycling/stabilisation work may proceed.

Sub-grade instability: Where sub-grade instability is identified during the recycling process, it shall be treated by:

- recovering the material in the pavement layers overlying the unstable material by either milling or excavating and loading into trucks for transport to temporary stockpile;
- excavating the unstable material to the depth directed by the Engineer and disposal;
- treating the exposed roadbed, as directed by the Engineer; and
- backfilling the excavation using material from both temporary stockpile and imported. Backfilling shall be undertaken in 15 cm (nominal) thick layers, compacted to the relevant density target that will be directed by the Engineer. Successive layers shall be constructed until the level of the existing road is reached. The top two layers (30 cm) shall be constructed with stockpiled material, a portion of which shall then be recycled and stabilised.

Where the measures described above are deemed necessary, the Engineer will detail the requirements for the depth of excavation, treatment of the exposed roadbed, the quality of material to be imported as backfill and density requirements.

Stockpiling the Treated Material: The mixed product may be transported to site and paved immediately or placed in stockpile for later use. Where it is placed in stockpile, care shall be taken to ensure that the following minimum requirements are met:

– the area on which the material is stockpiled shall be carefully prepared to avoid contamination from any source;

– the maximum height of stockpiled material shall be 3 m;

– moisture loss from the material in stockpile shall be prevented, either by covering the entire stockpile with an impervious sheet, or by spraying the surface of the stockpile with water every two hours between sunrise and sunset;

– no vehicles, front-end loaders or other equipment shall be permitted to drive on stockpiled material. Stockpiled material shall be maintained in as loose a state as is practical;

– samples shall be extracted from the stockpiled material seven (7) days after being placed in stockpile and, thereafter, every seven (7) days whilst the material remains in stockpile. Such samples shall be tested for moisture content and indirect tensile strength. Samples shall be taken from each 500 mm horizon below the surface of the stockpile to a maximum depth of 2 m;

– no material shall remain in stockpile for more than thirty (30) days unless the contractor can show by means of laboratory tests that keeping the material in stockpile for longer periods is not detrimental to the performance expectations of the final base course; and

– loading material from stockpile shall be undertaken by front-end loaders running on a thin layer of sacrificial mix on the stockpile floor. Loading shall be done in such a manner that the material is extracted from the base of a vertical face, thereby promoting mixing as the face collapses. All due care and diligence will be required by the contractor regarding the safety of plant and personnel during loading operations and to ensure that the stockpile is “made safe” at the end of work each day.

Appendix I to Annex 1

MIX DESIGN PROCEDURE FOR FOAMED BITUMEN STABILISATION

A1.1 Equipment Requirements

The mix design procedure for foamed bitumen stabilisation requires a laboratory unit capable of producing foamed bitumen at a rate of between 50 g and 200 g per second. The method of production shall closely simulate that of full scale production of foamed bitumen on the recycling machine. The apparatus shall have a thermostatically controlled kettle capable of holding a mass of 10 kg of bitumen at a constant temperature between the range of 160ºC and 200ºC, ± 5ºC. The unit shall have an expansion chamber similar to that on the recycling machine in which cold water is injected into hot bitumen. Water injection shall be variable from 0 to 5% (by mass of the bitumen) with an accuracy of 0.25%. The plant shall capable of accurately discharging a predetermined mass of foamed bitumen directly into the mixing bowl of an electrically driven laboratory mixer with a minimum capacity of 10 kg.

A1.1.1 *Calibration of the Bitumen Flow Rate*

For each different bitumen type and at each selected operating temperature, the rate at which bitumen is discharged into the expansion chamber shall be determined for pre-set discharge times ranging from 1 second to 10 seconds in 2 second intervals. This is achieved by discharging bitumen through the expansion chamber and into a sized bucket at each different pre-set time interval. The mass of bitumen for each time interval is determined by weighing and a graph of discharge vs. time plotted. This graph is used later to determine the time required to inject a specific amount of bitumen into a mix.

A1.1.2 *Checking the Water Flow Rate*

The water flow rate is controlled by a manometer that is pre-set at the required flow rate (in litres/hr.). This is checked by setting the manometer at different flow rates and weighing the water that is discharged through the expansion chamber for a fixed period of time (normally 30 seconds).

A1.2 Determination of the Foaming Characteristics of Bitumen

The foaming properties of each bitumen type are characterised by:

Expansion Ratio. A measure of the viscosity of the foamed bitumen, calculated as the ratio of the maximum volume of the foam relative to the original volume of bitumen; and

Half Life. A measure of the stability of the foamed bitumen, calculated as the time taken in seconds for the foam to collapse to half of its maximum volume.

The objective is to determine the temperature and percentage of water addition that is required to produce the best foam properties (maximum expansion ratio and half-life) for particular bitumen. This is achieved at three different bitumen temperatures as follows:

Laboratory scale foam bitumen plant

Step 1 Heat the bitumen in the kettle of the laboratory unit with the pump circulating the bitumen through the system until the required temperature is achieved (normally starting with 160°C). Maintain the required temperature for at least 10 minutes prior to commencing with testing.

Step 2 Set the water flow-meter to achieve the required water injection rate (normally starting with 2% by mass of the bitumen).

Step 3 Discharge foamed bitumen into a preheated (± 75 °C) steel drum (27.5 cm in diameter) for a calculated spray time for 500 g of bitumen. Immediately after the foam discharge stops, start a stopwatch.

Step 4 Using a calibrated dipstick, measure the maximum height the foaming bitumen achieves in the drum. This is recorded as the maximum volume.

Step 5 Use the stopwatch to measure the time in seconds that the foam takes to dissipate to half of its maximum volume. This is recorded as the foamed bitumen's half-life.

Step 6 Repeat the above procedure three times, or until similar readings are achieved.

Step 7 Repeat steps 3 to 6 for a range of at least three water injection rates. Typically, values of 2 %, 3% and 4% by mass of bitumen are used.

Step 8 Plot a graph of the expansion ratio versus water injection rate and half-life versus water injection rate on the same set of axes (see the example in Fig. A1.1). The optimum water addition is chosen as an average of the two water contents required to meet the minimum specified foaming properties.

Step 9 Repeat steps 1 to 8 at two other bitumen temperatures (normally 170 °C and 180 °C).

A: Minimum acceptable expansion

B: Minimum acceptable half-life

C: Equidistant

Opt: Water injection required to achieve maximum expansion and half-life

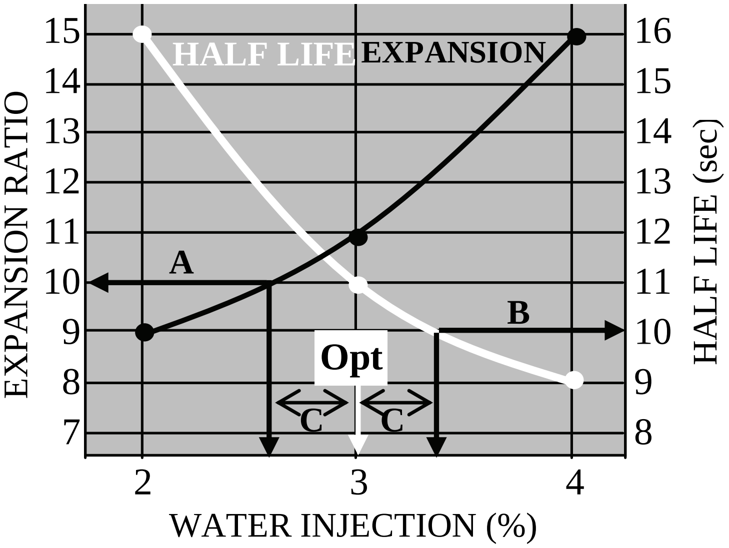


Fig. A1.1 Determination of the Optimum Water Addition.

An example.

The temperature and the water injection rate selected shall be the lowest that produces foam with properties in excess of the minimum specifications.

Notes.

1. The temperature range for bitumen (prior to foaming) shall be a minimum of 160°C to a maximum of 200°C.
2. The maximum water injection rate shall be 5% by mass of bitumen.
3. The minimum foaming properties that are acceptable for effective stabilisation are:

   Expansion ratio: 8-10 times

   Half-life: 6 seconds

   If these minimum properties cannot be achieved within the limits stated in Notes 1 and 2, the bitumen shall be deemed to be unacceptable for use in foamed bitumen stabilisation.

A1.3 Sampling and Preparation

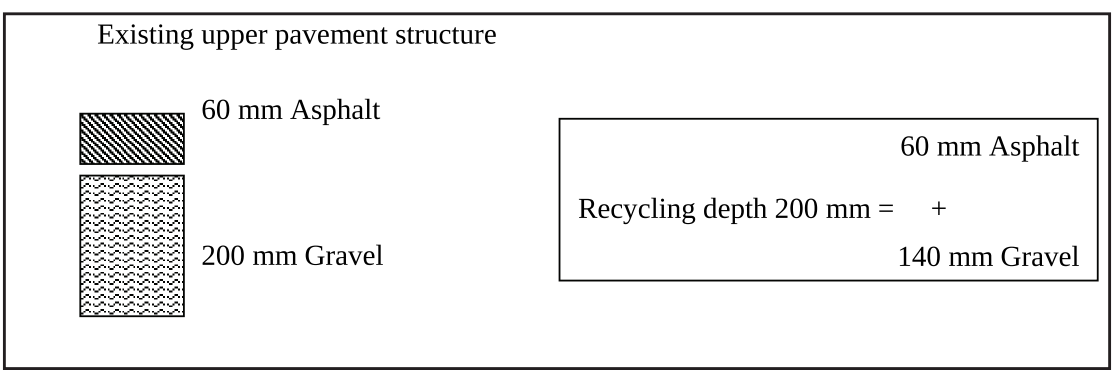
A1.3.1 *Field Sampling*

A1.3.1.1 In-situ Treatment: Where the depth of recycling is fixed, bulk samples (± 200 kg) of material from the recycling horizon are to be obtained from site using a recycler operating at normal speeds and settings. Where the depth of recycling is not known, field sampling shall follow the procedures described below for In-plant Treatment.

A1.3.2 In-plant Treatment: Bulk samples shall be obtained during field investigations and test pit excavations. The layers in the upper pavement (± 300 mm) shall be sampled separately. A milling machine or recycler shall be employed for sampling layers of bound material (Bituminous and previously bound layers). At least 150 kg of material shall be sampled from each layer that may be included in the mix design.

A1.3.2.1 Sample blending

Where necessary, blend the materials sampled from the different layers or from different sources to obtain a combined sample representing the material that will be stabilised. The in-situ density of field samples from different layers must be considered when blending materials, as illustrated in the boxed example below. Repeat the tests described in A1.2.1 above to determine the grading and plasticity index of the blended sample.



To obtain a representative mix, the two materials from the above example are blended in proportion to layer thickness and in-situ density as follows:

Material	Per square metre (kg)	Proportion	Per 10kg sample (g)
Bitumen (60 mm at 2300 kg/m³)	0.06 x 2300 = 138	138/418 = 0.33	0.33 x 10000 = 3300
Gravel (140 mm at 2000 kg/m³)	0.14 x 2000 = 280	280/418 = 0.67	0.67 x 10000 = 6700
Total	418	1.00	10000

A1.3.3 *Preparation of Samples for Mix Design Procedure*

A1.3.3.1 Standard soil tests

Determine the grading (IS 2386 Part 1), plasticity index (IS 2720 (Part 5)) and moisture/density relationship (IS 2720 (Part 8) for the sampled or blended material that is to be stabilised.

A1.3.3.2 Representative proportioning

Separate the material into the following four fractions:

Retained on the 19.0 mm sieve;

Passing the 19.0 mm sieve, retained on the 13.2 mm sieve;

Passing the 13.2 mm sieve, retained on the 4.75 mm sieve; and

Passing the 4.75 mm sieve.

Reconstitute representative samples in accordance with the grading (determined in A1.3.2.1 above) up to the portion passing the 19.0 mm sieve. Substitute the portion retained on 19.0 mm sieve with material that passes the 19.0 mm sieve, but is retained on the 13.2 mm sieve. The example in the table below explains this procedure:

Sieve analysis		Quantity of material to be added for 10 000 g sample		
Sieve Size (mm)	Percentage Passing from sieve analysis	Passing 4.75 mm	Passing 13.2 mm Retained 4.75 mm	Passing 19.0 mm Retained 13.2 mm
19.0	90.5	(53.6/100*10000) = 5360g	((72.3-53.6)/100*10000) = 1870g	((100-72.3)/100*10000 = 2770g
13.2	72.3			
4.75	53.6			

If there is insufficient material for substituting that retained on the 19.0 mm sieve (i.e. material passing the 19.0 mm sieve but retained on the 13.2 mm sieve), then lightly crush the material retained on the 19.0 mm sieve to provide more of this fraction.

A1.3.3.3 Sample quantities

The guidelines shown in the table below should be used for estimating the quantity of material required for the respective tests:

Test	**Sample Quantity Required**
Gradation (IS 2386 (Part1)) and Plasticity Index (IS 2720 (Part 5))	2 kg
Moisture/density relationship (IS 2720 (Part 8))	5 x 7 kg
Bituminous stabilisation design (100 mm diameter Marshall briquettes)	Minimum 10 kg per stabiliser content
Moisture contents	Approximately 1 kg

A1.3.3.4 Hydroscopic moisture content

Two representative air-dried samples, each approximately 1 kg, are used to determine the hygroscopic (air dried) moisture content of the material. (Note: Larger sample size should be used for more coarsely graded materials.) Weigh the air-dried samples, accurate to the nearest 0.1 g, and then place them in an oven at a temperature of between 105ºC and 110ºC until they achieve constant mass. The hygroscopic moisture content is the loss of mass expressed as a percentage of the dry mass of the sample.

A1.3.3.5 Active Filler Requirements

Bitumen stabilisation is normally carried out in combination with a small amount of active filler (cement or hydrated lime) to improve dispersion of the bitumen. The improved dispersion contributes to increased soaked strengths.

Although the use of active fillers is recommended, in parts of the world, these agents are not readily available. In such cases, the use of crusher dust (minus 6 mm crusher tailings) or similar material can be used.

For good quality materials, with retained strengths in excess of 80%, additional tests without active filler should be carried out during the mix design process. The results of these tests will allow a decision to be made as the whether the addition of an active filler is warranted.

The following application rates (by mass) of hydrated lime or cement should be used as a guide.

Plasticity Index < 10	Plasticity Index 10 – 16	Plasticity Index > 16
Add 1% ordinary Portland cement	Add 1% hydrated lime	Pre-treat with 2% hydrated lime

Pre-treatment requires that the lime and water be added at least 4 hours prior to the addition of the foamed bitumen. The treated material must be placed in an air-tight container to retain moisture. However, due to the hydration process, the moisture content should always be checked and, if necessary, adjusted prior to adding the bitumen stabilising agent.

A1.4 Mixing the Prepared Samples with Foamed Bitumen

Step 1 Place the required quantity of sample into a suitable mixing container (capacity > 10kg).

Step 2 Determine the dry mass of the sample using equation A1.1

$$\boxed{M_{sample} = \frac{M_{air-dry}}{\left(1+\left(\frac{W_{air-dry}}{100}\right)\right)}} \qquad \text{[Equation A1.1]}$$

where M_{sample} = dry mass of the sample [g]

$M_{air\text{-}dry}$ = air-dried mass of the sample [g]

$W_{air\text{-}dry}$ = moisture content of air-dried sample [% by mass]

Step 3 Determine the required mass of active filler (lime or cement) using equation A1.2.

$$\boxed{M_{Cement} = \frac{C_{Add}}{100} * \left(M_{sample}\right)} \qquad \text{[Equation A1.2]}$$

where M_{Cement} = mass of lime or cement to be added [g]

C_{add} = percentage of lime or cement required [% by mass]

M_{sample} = dry mass of the sample [g]

Step 4 Determine the percentage water to be added for optimum mixing moisture content as calculated using equation A1.3. The mass of water to be added to the sample is then determined using equation A1.4.

$$\boxed{W_{add} = W_{OMC} - W_{air-dry} - (W_{OMC} * 0.5 - 1)} \qquad \text{[Equation A1.3]}$$

$$\boxed{M_{Water} = \frac{W_{add}}{100} * \left(M_{sample} + M_{Cement}\right)} \qquad \text{[Equation A1.4]}$$

where W_{add} = water to be added to sample [% by mass]

W_{OMC} = optimum moisture content [% by mass]

$W_{air\text{-}dry}$ = water in air-dried sample [% by mass]

Step 5 Mix the material, active filler and water in the mixing bowl until uniform.

Note: Inspect the sample after mixing to ensure that the mixed material is not packed against the sides of the mixer. If this situation occurs, mix a new sample with a lower moisture content. Check to see that the material mixes easily and remains in a "fluffy" state. If any dust is observed at the end of the mixing process, add small amounts of water and remix until a "fluffy" state is achieved with no dust.

Step 6 Determine the mass of foamed bitumen to be added using equation A1.5:

$$M_{Bitumen} = \frac{B_{add}}{100} * \left(M_{Sample} + M_{Cement}\right) \quad \text{[equation A1.5]}$$

where $M_{Bitumen}$ = mass of foamed bitumen to be added [g]

B_{add} = foamed bitumen content [% by mass]

M_{Cement} = mass of lime or cement to be added [g]

M_{sample} = dry mass of the sample [g]

Step 7 Set the timer for bitumen addition according to the following formula:

$$T = factor * \left(\frac{M_{Bitumen}}{Q_{Bitumen}}\right) \quad \text{[equation A1.6]}$$

where T = time to be set for foaming [s]

$M_{Bitumen}$ = mass of foamed bitumen to be added [g]

$Q_{Bitumen}$ = bitumen flow rate (See A1.1.1) [g/s]

factor = compensation for bitumen losses on mixing arm and bowl of the Hobart mixer. Experience shows that a factor of 1,1 is generally required. This factor is taken as 1.0 with the pugmill mixer.

Step 8 Position the mechanical mixer adjacent to the foaming unit so that the foamed bitumen can be discharged directly into the mixing bowl.

Step 9 Start the mixer and allow it to mix for at least 5 seconds before discharging the required mass of foamed bitumen into the mixing bowl. Continue mixing for a further 30 seconds after the foamed bitumen has discharged into the mixer.

Step 10 Determine the mass of water required to bring the sample to 90% of the optimum moisture content using equation A1.7.

$$M_{plus} = \frac{0.9W_{OMC} - W_{Sample}}{100} * \left(M_{Sample} + M_{Cement}\right) \quad \text{[Equation A1.7]}$$

where	M_{plus}	= mass of water to be added	[g]
	W_{OMC}	= optimum moisture content	[% by mass]
	W_{sample}	= moisture content of prepared sample	[% by mass]
	M_{sample}	= dry mass of the sample	[g]
	M_{cement}	= mass of lime or cement to be added	[g]

Step 11 Add the additional water and mix until uniform.

Step 12 Transfer the foamed bitumen treated material into a container and immediately seal the container to retain moisture. To minimise moisture loss from the prepared sample, manufacture briquette specimens as soon as possible.

Repeat the above steps for at least four different foamed bitumen contents.

A1.5 Manufacture of 100 mm Diameter Briquette Specimens

Step 1 Prepare the Marshall mould and hammer by cleaning the mould, collar, base-plate and face of the compaction hammer. Note: the compaction equipment must not be heated but kept at ambient temperature.

Step 2 Weigh sufficient material to achieve a compacted height of 63.5 mm ± 1.5 mm (usually 1.15 kg is adequate). Poke the mixture with a spatula 15 times around the perimeter and 10 times on the surface, leaving the surface slightly rounded.

Step 3 Compact the mixture by applying 75 blows with the compaction hammer (taking care to ensure the continuous free fall of the hammer).

Step 4 Remove the mould and collar from the pedestal and invert (turn over).

Replace it on the pedestal and press down firmly to ensure that it is secure on the base plate. Compact the other face of the briquette with a further 75 blows.

Step 5 After compaction, remove the mould from the base-plate and extrude the briquette by means of an extrusion jack

Note: With certain materials lacking cohesion, it may be necessary to leave the specimen in the mould for 24 hours, allowing sufficient strength to develop before extracting.

A1.6 Curing the Briquette Specimens

Place the briquettes on a smooth flat tray and cure in a suitable oven at 40°C until a constant mass has been achieved (normally 72 hours in a properly-packed forced-draft oven is required). Remove from oven after curing and allow to cool to 25°C.

A1.7 Determination of Bulk Density

After cooling, for each briquette:

Step 1 Determine the mass.

Step 2 Measure the height at four evenly-spaced places around the circumference and calculate the average height.

Step 3 Measure the diameter.

Step 4 Calculate the bulk density using equation A1.8

$$BD = \frac{4 * M_{Briq.}}{\pi * d^2 * h} * 10000 \quad \text{[Equation A1.8]}$$

where	BD	= bulk density	[kg/m³]
	$M_{Briq.}$	= mass of briquette	[g]
	h	= average height of briquette	[cm]
	d	= diameter of briquette	[cm]

Exclude from further testing any briquette whose bulk density differs from the mean bulk density of the batch by more than 50 kg/m³.

Note: The bulk density can be verified by using the "weigh-in air / weigh-in water" method

A1.8 Strength Test Procedures

A1.8.1 *Determination of Indirect Tensile Strength (ITS)*

The ITS test is used to test the briquettes under two different moisture conditions: dry and soaked. The ITS is determined by measuring the ultimate load to failure of a briquette that is subjected to a constant deformation rate of 50.8 mm/min on its diametrical axis. The procedure is as follows:

Step 1 Place the briquette onto the ITS jig. Position the sample such that the loading strips are parallel and centred on the vertical diametrical plane.

Step 2 Place the transfer plate on the top bearing strip and position the jig assembly centrally under the loading ram of the compression testing device.

Step 3 Apply the load to the briquette, without shock, at a rate of advance of 50.8 mm per minute until the maximum load is reached. Record the maximum load P (in kN), accurate to 0.1 kN.

Step 4 Immediately after testing a briquette, break it up and take a sample of approximately 1000 g to determine the moisture content (W_{break}).

Step 5 Calculate the ITS for each briquette to the nearest 1kPa according to equation A1.9:

$$\boxed{ITS = \frac{2 * P}{\pi * h * d} * 1000}$$ [Equation A1.9]

where: ITS = Indirect Tensile Strength [kPa]

P = maximum applied load [kN]

h = average height of the specimen [cm]

d = diameter of the specimen [cm]

Step 6 To determine the soaked ITS, place the briquettes under water at 25 °C ± 1°C for 24 hours. Remove briquettes from water, surface dry and allow to stand on a draining board at 25 °C ± 1°C for 30 minutes. Repeat steps 1 to 5 for each briquette.

Step 7 Determine the Unsoaked ITS (ITS_{DRY}) and Soaked ITS (ITS_{SOAKED}) for each batch of briquette specimens by calculating the respective averages.

$$\boxed{TSR = \frac{ITS_{SOAKED}}{ITS_{DRY}} * 100}$$ [Equation A1.10]

A1.9 Interpretation of Test Results

To determine the "optimum foamed bitumen content", plot the ITS_{DRY} values, the ITS_{SOAKED} values and the TSR values (three curves) versus the added foamed bitumen (see example below in **Fig.** A1.2).

The foamed bitumen added value that best meets the desired properties is regarded as the optimum foamed bitumen content. The desired properties are project specific, taking into account the type of material that is stabilised with foamed bitumen and the moisture regime. **As a guideline, the minimum ITS_{DRY} value for all pavements with a structural capacity in excess of 0.3 million ESALs shall be 225 kPa and Soaked ITS should be 100 KPa.**

Minimum Strength Requirement of RBM Mixes for foam Bitumen.

Strength Test	Specimen diameter	Minimum strength, KPa
ITS_{dry}, 25°C	100 mm	> 225 kPa
ITS_{wet} 25°C	100 mm	> 100 kPa

Gradation of RBM Mixes (IRC 37-2012)

Sieve size, mm	%passing
45	100
37.5	87-100
26.6	77-100
19	66-99
13.2	57-87
4.74	33-50
2.36	25-47
0.60	12-27
0.3	8-21
0.075	2-9

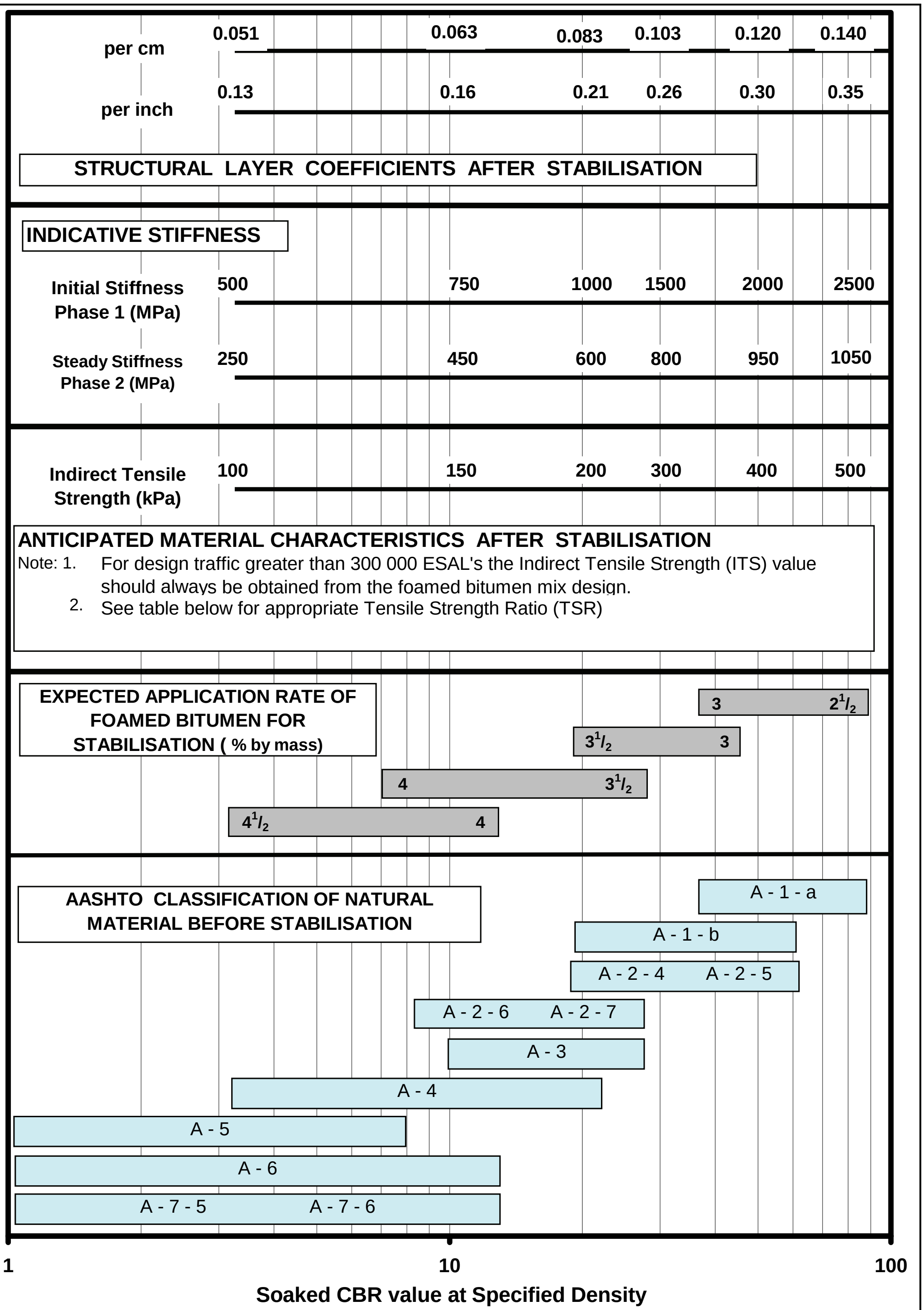
The recommended TSR values for different climatic conditions and terrain are shown in the table below.

Terrain / drainage conditions	Mean Annual Rainfall (MAR) in mm			
	Arid MAR < 300	Dry 300< MAR <600	Moderate 600 <MAR <1000	Wet MAR > 1000 mm
Rolling/well drained	25	50	60	70
Flat/poorly drained	50	60	70	80

ITS value at the optimum foamed bitumen addition can be used in **Fig.** A1.3 to obtain an indicative value for the Structural Layer Coefficient and Resilient Modulus value for evaluating the structural capacity of the rehabilitation proposal. Using this **Fig.**, the input values for pavement design for the example in **Fig.** A1.2 would be:

Structural layer coefficient:	**0.27 per inch**
Resilient modulus:	**1600 MPa initial/900 MPa-1000 MPa steady state**

Fig. A1.3 Structural Guidelines for Foamed Bitumen Stabilised Material



Notes

1. All materials classified as A - 4 or lower to be pretreated with hydrated lime
2. Cement at nominal 1% to be added to all materials with PI <10 and CBR <45
3. Where required, non-plastic fine material to be added to increase the percentage passing the 0.075mm sieve to achieve a minimum of 5%.
4. The following Tensile Strength Retained (%) requirements are recommended;

Appendix II to Annex 1

QUALITY ASSURANCE TESTING FOR FOAMED BITUMEN STABILISED LAYERS

A2.1 Scope

This Annexure covers the requirements for monitoring the quality of foamed bitumen stabilised layers and describes the routine tests to be carried out together with the frequency of such testing.

A2.2 Daily Production Record

Daily production records shall be kept for detailing the production achieved.

A2.2.1 *In-situ Treatment:*

The following details shall be included for each recycled cut:

- cut number
- start and end chainage;
- depth of recycling;
- width of overlap(s) with previous cut(s);
- temperature of the bitumen;
- the foaming characteristics of each tanker-load of bitumen used;
- temperature of the material exposed on the milled-out floor; and
- the quantity of bitumen and filler consumed.

A2.2.2 *In-plant Treatment:*

The following details shall be included:

a) Production (where different blends were mixed, by blend)

- blend proportions and description of materials in the mix;
- application rates for bitumen and filler;
- temperature of the input materials and bitumen;
- the foaming characteristics of the bitumen used;
- tonnage of material treated and destination (stockpile and/or site); and
- reconciliation of actual consumption of bitumen and filler;

b) Location of where the treated material was used on the project

- start/end chainages and width of paving;
- thickness of paved layer (after compaction);
- ambient temperature whilst paving; and
- temperature of the treated material when paved;

A2.2.3 As-built Data Records: Records shall be compiled which will schedule the daily production data, as above, together with the results of all relevant quality assurance testing for that particular day's production.

A2.3 Quality Requirements

The material/structural properties to be controlled and the frequency of testing are:

Material/ Structure	Test	Test Method	Quantity	No of tests (minimum)
Bitumen	Penetration grade Foaming characteristics	Delivery ticket Visual – see below	Per tanker	1
Bitumen stabilised layer	Layer thickness	Measurements	See below	
	Compaction	IS 2720 (Part 28)	Batch (note 1)	4
Foamed bitumen stabilised material	Moisture content determination	IS 2720 (Part 2)	Batch (note 1)	4
	Moisture/density relationship	IS 2720 (Part 8)	Batch (note 1)	1
	Strength characteristics	ITS – see below	Batch (note 1)	2

Note 1: A Batch shall constitute a day's work or as determined by the Engineer.

A2.3.1 *Foaming characteristics*

The test nozzle on the in-situ recycler or in-plant mixer shall be used to check the foaming characteristics of each tanker-load of bitumen that is consumed. A quantity of foamed bitumen is injected from the test nozzle into a straight-sided container (normally a 5-second sample). The half-life is measured by taking the time for the foamed bitumen to reduce in volume to half the height of the maximum expansion noted in the container. The container is then set aside for at least 30 minutes or until the foamed bitumen has subsided completely and the unexpanded volume of the quantity of bitumen injected into the container is noted. The expansion ratio is the ratio of the maximum expansion to the unexpanded volume where the unexpanded volume is taken as one unit.

A2.3.2 *Depth of Recycling/Thickness of the Compacted Layer*

The thickness of the completed layer shall be determined at each density test location from physical measurements of the excavated hole. In addition, 100 mm diameter cores may be extracted and measured after a curing period of at least two weeks.

A2.3.3 *Compaction of the Completed Layer*

The in situ density of the full thickness of the compacted layer shall be determined using the sand replacement method (IS 2720 (Part 28)).

A2.3.4 *Strength Characteristics from Field Samples*

The quality and uniformity of the foamed bitumen stabilised layer shall be assessed from samples taken on site, before compaction is applied. At least one bulk sample (±100 kg) shall be taken from the full depth of the layer for every 1500 m² of treated material. All samples must be retained in sealed bags for immediate transport to the laboratory. Field samples shall be taken to the laboratory within two hours of sampling and 100 mm diameter briquette specimens manufactured within four hours of being sampled. The procedures described below shall be followed.

A2.3.4.1 Determination of the Moisture/Density Relationship

The Maximum Dry Density and Optimum Moisture Content (OMC) are determined from a representative sample as per the moisture-density relationship test (IS 2720 (Part 8)). (Generally one test per day is undertaken, unless a significant change in the material blend is noted, demanding that one test per material blend is carried out.)

A2.3.4.2 Manufacturing Briquette Specimens

The material for manufacturing the briquette specimens shall be prepared as follows;

i) Determine the moisture content of the field sample.

ii) Weigh out a 10 kg sample (sufficient for manufacturing 6 briquettes).

iii) Sieve the sample through the 19 mm sieve and determine the mass retained on the 19 mm sieve.

iv) Using a portion of the remaining field sample, extract the material retained on the 12.5 mm sieve but passing the 19 mm sieve.

v) Weigh out an amount equal to the mass of material retained on the 19 mm sieve from the original 10 kg sample and add this to the sample such that the mass once again totals 10 kg.

vi) Adjust the moisture content of the sample to approximate the OMC.

vii) Manufacture six 100 mm diameter briquettes following the procedures described under Item A1.5 in Annexure 1.

A2.3.4.3 Curing the Briquette Specimens

The procedures described under Item A1.6 in Annexure 1 shall be followed for curing the briquettes.

A2.3.4.4 Determination of Bulk Density

Follow the procedures described under Item A1.7 in Annexure 1 for determining the bulk density of each briquette.

A2.3.4.5 Determination of the Indirect Tensile Strength (ITS)

The procedures described under Item A1.8 in Annexure 1 shall be followed for determining the ITSDRY and ITSSOAKED values and the resulting TSR value. These values are then used to determine whether the material has met the minimum specified requirements.

A2.3.5 *Strength Characteristics from Core Specimens*

Not sooner than 21 days after completing the foamed bitumen stabilised layer, 100 mm diameter core samples may be extracted from the full thickness of the layer and tested for ITS values

A2.3.5.1 Extracting Core Samples

Only core barrels in good condition shall be used to extract samples of foamed bitumen stabilised material. A minimum amount of water shall be added whilst drilling and the rate of penetration of the barrel will be sufficiently slow to prevent damaging the sample. After extraction, core specimens shall be handled with care to prevent breakage.

A2.3.5.2 Cutting Core Specimens

A rotary saw fitted with a large diameter diamond-tipped blade shall be used to cut 63 mm high specimens from the portion of the core that suffered least damage during extraction and handling. Where possible, more than one specimen should be cut from each core sample.

A2.3.5.3 Curing the Core Specimens

The procedures described under Item A1.6 in Annexure 1 shall be followed for curing the core specimens.

A2.3.5.4 Determination of Bulk Density

The procedures described under Item A1.7 in Annexure 1 shall be followed for determining the bulk density of each core specimen.

A2.3.5.5 Determination of the Indirect Tensile Strength (ITS)

The procedures described under Item A1.8 in Annexure 1 shall be followed for testing the core specimens to determine the ITS_{DRY} and ITS_{SOAKED} values and the resulting TSR value. These values are then used to determine whether the material has met the minimum specified requirements.

Note. Where the ITS results for briquette specimens are in conflict with those obtained from core specimens, the core specimen results after drying sufficiently (to below 75% of the OMC), the shape of the original surface shall be reinstated by grader and compacted to achieve a nominal 95% of the maximum dry density determined as per IS 2720 (Part 8). Thereafter, the recycling / stabilisation work may proceed.

Appendix III to Annex 1

MANAGING THE RECLAIMED BITUMINOUS MATERIALS (RBM)

A 3.1 Managing the Reclaiming Process

RBM may be obtained from several sources. The most common method is through cold milling operations, also known as cold planning/ Milling. Two other sources of RBM are full-depth pavement demolition and bituminous plant waste. This section discusses the different types of RBM sources.

A 3.2 Plant Waste

All bituminous plant operations generate some waste during plant start-up, transition between mixes, and clean-out. Generally, start-up and shut-down plant wastes have very low bituminous contents. Another form of waste is mix rejected from a project due to incomplete coating or due to the mix temperature being too high or too low for the job. Other situations that may result in wasted mix include trucks loaded with too much mix to finish the job or mix that could not be placed due to inclement weather. These waste materials are often stockpiled for later processing into a recyclable material. Since these waste mixes have not been subjected to environmental aging from years of service, the bituminous binder is less aged than RBM recovered from a road. Waste materials also have fewer fines than other sources of RBM since it was not milled or broken up during demolition. However, waste materials must be thoroughly mixed and processed to make them into uniform, recyclable materials. Waste materials are often combined with other sources of RBM in multiple-source stockpiles. Processing RBM from multiple sources is discussed in greater detail in the next section.

A 3.3 Contamination

It is important that stockpiles be kept free of contaminants from the beginning. It easy to understand how bad perceptions of RBM form when there is dirt, rubbish, or vegetation in RBM stockpiles, or when trash is found in the mix when it shows up on the job site or pops out of the pavement a few days after paving. Treat RBM stockpiles as the most valuable material on the plant yard—because they are. Truck drivers bringing materials onto the plant yard must be clearly instructed where to dump their loads so that unwanted construction debris does not end up in the RBM stockpile and instructed that they should clean the truck beds before hauling millings or useable RBM. The plant QC personnel and the loader operator should also continuously monitor unprocessed and processed RBM stockpiles to make sure they do not contain deleterious materials. If contaminants are found, dig them out immediately so that they are not covered up with other RBM brought onto the yard.

A 3.4 Processing and Crushing RBM

The basic goals of processing RBM are to

1) create a uniform stockpile of material from a collection of different RBM materials from various sources,

2) separate or break apart large agglomerations of RBM particles to a size that can be efficiently heated and broken apart during mixing with the virgin aggregates,

3) reduce the maximum aggregate particle size in the RBM so that the RBM can be used in surface mixes (or other small nominal maximum aggregate size mixtures), and

4) minimize the generation of additional P 200 (i.e., dust).

A 3.5 Processing Milling Material.

Milled Material stock pilled after Milling

Millied Material. from a single project are usually very consistent in gradation, bituminous content, aggregate properties, and binder properties. Therefore, processing millings may only be necessary to achieve Goals #2 or #3. However, as noted previously, a common limitation to increasing RBM contents in bituminous mixtures is the dust content in the RBM. Since milled RBMs already contain appreciable amounts of P 200 (typically between 10% and 20%) due to the milling of the material from the roadway, it is best to minimize further crushing of milled RBM whenever possible. Therefore, when a contractor obtains a large quantity of millings from a single project, it is considered a best practice not to further crush this material, but rather to use it “as-is” in mix designs or to screen the millings to remove larger particles.

Asphalt material Reclaimed by Milling Machine

A 3.6 Millings: Recommended Processing Options

1. Receive millings from project.
2. Sample and test a few locations of the millings stockpile to determine the as-received gradation and check the maximum aggregate size.
3. If the maximum aggregate size of the as-received millings is small enough to use in the desired mix design(s), do not further process the millings.
4. If maximum particle size is too large for desired mix(es), then either fractionate the RBM over a screen equal to or smaller than the NMAS of desired mix(es). Stockpile the fine RBM (portion passing through the screen) and test for properties, as described in Section

    a. Stockpile the coarse RBM fraction(s) into separate stockpile(s) for use in other, larger NMAS mixes, or

    b. crush the millings so that they will pass the desired screen size.

This is the least desirable option because it will result in more uncoated faces of RBM particles and generate additional dust, which can severely hamper how much of the crushed RBM can be used in mix designs. When a contractor wants to increase RBM contents but is often limited by VMA requirements or the dust-to binder ratio during mix designs, Para 4 must become a primary consideration in his RBM-processing plan.

A 3.7 Processing RBM from Multiple Sources

RBM materials from multiple sources that have different compositions must be processed to create a uniform material suitable for use in a new bituminous mixture. All around the world, contractors have found that they can make a very uniform and high quality RBM from a combination of pavement rubble, millings, and wasted mix. The key to achieving a consistent RBM from multiple sources is careful bending as part of the processing operations. A bulldozer, excavator, or similar equipment should be used to blend materials from different locations in the multiple-source RBM stockpile as it is fed into the screening and crushing operation. This will tend to “average-out” variations in the RBM from different sources. The site WMM Plant should be used for effective blending of the RBM to obtain homogeneous mix.

A 3.8 Screening RBM during Processing

Since crushing RBM will create more aggregate fines, it is best to set up the crushing operation so that the RBM is screened before it enters the crusher. This will allow the finer RBM particles that pass through the screen to bypass the crusher. **Fig.** 8 shows a portable RBM crushing unit that is equipped with a screen deck in line before the crusher. Only the RBM particles retained on the screen will pass through the crusher.

Some RBM crushing units are set up so that all of the RBM is conveyed from the feeder bin into the crusher, followed by a recirculation circuit after the crusher. The recirculation circuit is designed to return larger particles that do not pass through the screen back to the crusher. However, since all of the material must go through the crusher in the first pass, there is a good chance that breakdown will occur for some smaller particles that did not need to be reduced in size.

A 3.9 Crusher Types

A variety of crusher types are used for crushing RBM. Many contractors have found that the best type of RBM crushers are Track Mounted / horizontal-shaft impactors (HSI) with inbuilt pre-screen and inbuilt product screen so that desired over size product can be sent back to the crusher for further crushing to produce desired aggregate gradation.

The speed and clearance of hammer mill crushers can be adjusted to reduce aggregate crushing. Some contractors have used milling machines to crush stockpiled RBM. There may be a risk of the milling machine overturning since the stockpile is uneven and may not provide stable support for the heavy machine. No data are available regarding the effectiveness of this method of processing in terms of size reduction or consistency of the RBM. However these are subject to the following conditions:

Compression-type crushers such as jaw crushers, and cone crushers also are found effective for fine sizing RBM. Hammer mill crushers tend to generate more fines due to the retention of the material in the chamber. The speed and clearance of hammer mill crushers can be adjusted to reduce aggregate crushing. Some contractors have used milling machines to crush stockpiled RBM. There may be a risk of the milling machine overturning since the stockpile is uneven and may not provide stable support for the heavy machine. No data are available regarding the effectiveness of this method of processing in terms of size reduction or consistency of the RBM. However these are subject to the following conditions:

A 3.10 Weather

Moisture and temperature can affect crushing and screening of RBM. When the RBM is wet and/or temperatures are hot, RBM will be stickier and tend to build up in feeders and crushers, blind screens, and RBM fines will stick to belts and accumulate under conveyors. Not only does this require more maintenance of RBM processing units and RBM feeder systems for mix production, it can also affect the gradation and bituminous content of the RBM.

A 3.11 Fractionating

Fractionating is a process gaining popularity in which RBM is screened into typically two or three sizes. The sizes are typically 20 mm x 10 mm, 10 mm x 4.75 mm, and less than 4.75 mm. In some cases, the plus 20 mm size material is returned to a crusher, and the crushed material is then returned to the screening unit. The primary advantage of fractionating RBM is that having stockpiles of different RBM sizes provides more flexibility in meeting mix design requirements.

The decision of whether or not to fractionate RBM into different sizes should be the mix producer's choice and not a specification. Some agencies have recently begun to require RBM fractionation for higher RBM contents. This type of method specification is not appropriate; a better approach to assure consistency of RBM is to set limits on the variability of the RBM stockpiles.

A 3.12 Moving the Processed RBM Stockpiles

In most cases, processed RBM will be moved from the location it is screened and/or crushed to another location more convenient to feed into the bituminous plant. This is another opportunity to remix the material and improve its consistency. Using the loader to dig into the RBM stockpile at the processing unit at different locations around the pile and remixing loads while building the stockpile at the final location can again be used to average out variations.

A 3.13 Stockpiling to Minimize Segregation

As with virgin aggregates, there is a potential for RBM materials to become segregated in stockpiles. This is a common problem when stockpiles are built using fixed conveyors that allow the RBM particles to drop long distances to the stockpile. Larger particles have more kinetic energy and will tend to roll down toward the bottom of the stockpile. This results in more coarse particles with a lower bituminous content at the base of the stockpile and finer higher bituminous content RBM in the top of the stockpile. This problem can be minimized by using indexing-type conveyors that extend and raise the end of the conveyor as the size of the stockpile increases. If segregation is evident, a front end loader can be used to remix the stockpile.

A 3.14 Stockpiling to Minimize Moisture

Moisture content of aggregates and RBM is a primary factor affecting a bituminous plant's production rate and drying costs. Some contractors have implemented creative approaches to reducing moisture content in stockpiles. The best practice to minimize the accumulation of moisture in stockpiles is to cover the stockpile with a shelter or building to prevent precipitation from getting to the RBM. Second to that, it is a good practice to use conical stockpiles to naturally shed rain or snow, and to place the stockpile on a paved and sloped surface to help water drain from the pile. Irregular-shaped stockpiles with surface depressions that will pond water should be corrected by shaping the pile as it is being built with the front-end loader or a small dozer. However, the use of heavy equipment on the top of RBM stockpiles should be minimized to avoid compaction of the RBM. Likewise, it is also recommended that RBM stockpiles be limited to 3 m in height to reduce the potential for self-consolidation of the stockpile.

A 3.15 In-line RBM Crushers or Crusher Circuits

RBM crushers or crushing circuits that are built into the bituminous plant's RBM feed line can change the gradation of the RBM material being fed into the mix. Gradation test results on the stockpiled RBM then become meaningless, and the quality control personnel will have to make unnecessary, and probably substantial, mix adjustments to get the mix gradation and volumetric properties in specification during production start-up. In many cases, this could require a reduction in the RBM content in order to meet the quality control tolerances for the mix.

In-line roller crushers (also known as lump-breakers) and reduced-speed impact crushers designed to break up agglomerations of RBM rather than change the gradation are used by some contractors. It is recommended to conduct a simple extracted gradation check of RBM samples before and after the in-line crusher to determine if it is breaking down the RBM aggregate.

A 3.16 Advantages and Disadvantages of Different RBM Processing Options

Table 1 lists possible advantages and disadvantages of different RBM processing options.

Process	Possible Advantages	Possible Disadvantages
Use of Millings without Further Processing	• Avoids further crushing of aggregate particles in RAP, which may allow higher RAP contents in mixes • Lowest cost of RAP processing options • Millings from large projects are likely to have a consistent gradation and asphalt content	• Requires multiple RAP stockpiles at the plant • Millings from individual projects are different; therefore, when a particular millings stockpile is depleted, new mix designs must be developed with other RAP
Screening RAP Before Crushing	• Limits crushing of aggregate particles in RAP, which reduces dust generation	• Few RAP crushing and screening units are set up to pre-screen RAP
Crushing all RAP to a Single Size	• Allows the processed RAP to be used in many different mix types • Generally provides good uniformity from RAP materials obtained from multiple sources • Large RAP stockpiles can be generated for annual production	• Tends to increase the dust content of RAP stockpiles, which may limit how much RAP can be used in mix designs
Fractionating RAP	• Using different sized RAP stockpiles provides greater flexibility in developing mix designs	• Requires the most space for multiple smaller stockpiles • Most expensive processing option (cost of fractionation unit plus additional RAP cold feed bin) • May generate an excess of a RAP size if the mix designs are not balanced to the RAP feed

A 3.17 Sampling and Testing the RBM

This section provides guidance on the best methods and practices for sampling and testing RBM as part of a quality management program. A well-executed sampling and testing plan for RBM is necessary to assess the consistency of the RBM stockpiles and to obtain representative properties for use in mix designs.

A 3.18 RBM Variability

A common misconception exists that RBM stockpiles are highly variable and, thus, using higher RBM contents in new bituminous mixes will lead to more variability in the mixtures. However, well-managed RBM stockpiles have a more consistent gradation than virgin aggregates considering that RBM obtained from a single milling project in which the pavement was constructed of mixtures subject to high quality assurance standards, it is no surprise that the millings would have a consistent gradation, bitumen content, and binder properties. Less expected is how consistent RBM processed from multiple sources can also be just as consistent in gradation and bitumen content as millings.

Sampling and Testing Frequency

Sampling for at least one set of tests per 1,000 tons of RBM is considered a best practice. This is generally more frequent than is required for virgin aggregates, but is appropriate for a component that will comprise a large portion of a bituminous mixture. A minimum of 10 tests should be performed on a RBM stockpile to yield good statistics for consistency analyses.

A 3.19 Sampling Method

It is recommended that RBM stockpiles be sampled as they are being built at the location where they will be fed into the bituminous plant. Samples from the different locations should not be combined since the results from the different locations will be used to calculate variability statistics. Sampling at the time the stockpile is built will be easier and more representative of the stockpile compared to samples taken later, after a crust forms on the RBM stockpile. When a RBM stockpile has been in place for a while, it is generally difficult to dig into with a shovel. The best way to sample existing RBM stockpiles is with the assistance of a front-end loader, as described in Section X1.2 of AASHTO T2 or ASTM D 75-03. This method is described and illustrated below.

1. Use a front end loader to dig into to the ready to use RBM stockpile.
2. Empty the bucket on a clean surface to form miniature sampling stockpile
3. Use the loader to back blade across the top of the mini stockpile to create a flat surface
4. Mini stockpile ready to be sampled
5. Use a square-end shovel to obtain samples from the surface of the mini stockpile

6. Sample from three locations over the surface of the mini stockpile

7. Combine samples taken from the same mini stockpile. This sample will later be divided into test portions

8. Repeat this process to obtain samples at other locations around the RBM stockpile. Do not combine samples from different locations.

A 3.20 Test Methods

For mix designs using RBM, the data needed from tests on the RBM are

1) bituminous binder content of the RBM,

2) gradation of the aggregate recovered from the RBM,

3) bulk specific gravity of the RBM aggregate,

4) consensus properties of the aggregate recovered from the RBM, and

5) (for high RBM contents) the RBM bituminous binder properties.

6) more than 35% RBM cannot be used if fine milling has been carried out at site.

In some cases, additional aggregate tests may be necessary. For example, if the RBM is to be used in a surface mix for high-speed traffic, some agencies may require tests to evaluate the polishing or mineralogical composition of the RBM aggregate. Typically, source properties such as LA abrasion and sulfate soundness tests are not necessary since it is unlikely that the coarse aggregates in the RBM would have come from sources not originally approved by the state agency.

A recent joint study by the University of Nevada Reno and NCAT examined several options for testing RBM to determine the best methods for determining many of the properties noted above. Three methods were used to determine bitumen contents and recover the aggregates for aggregate property tests: the ignition method, the centrifuge extraction method, and the reflux extraction method. Trichloroethylene was used as the solvent in the centrifuge and reflux methods. The results of the study indicate that

- The ignition method yielded the most accurate bitumen contents for the RBM and provided the lowest testing variability compared to the solvent extraction methods.
- The centrifuge extraction method had the smallest affect on the gradations of the recovered aggregate.
- The combined bulk specific gravity of the aggregates recovered by the ignition method was closest to the original materials, except for the soft limestone aggregate. In that case, the aggregate recovered from the centrifuge extraction was closest to the original material.

- The sand-equivalent and fine-aggregate angularity values for aggregates recovered from all three methods were different from the original materials. No consistent biases were evident to warrant making adjustments to the tested results.
- LA abrasion values for aggregates recovered from the centrifuge extraction were closest to the original values.

Additional tests on the extracted and recovered bitumen binder from the RBM may be required for mix designs that will contain more than 25% RBM. Current best practices for determining RBM binder properties are described in Chapter 3 of NCHRP Report 452. Several research studies are currently in progress to develop alternative procedures for determining RBM binder properties and methods for selecting the grade of the virgin binder for high RBM content mixtures:

A 3.21 Methods for Determining RBM Bitumen Contents and Recovering Aggregates

Two options are recommended for determining RBM bituminous content and recovering aggregates: the ignition method and solvent extractions. Both methods have advantages and disadvantages. The following sections discuss the associated advantages and disadvantages of these methods.

A 3.22 Ignition Method

The most popular method for determining RBM bitumen contents and recovering aggregates for other tests is the ignition method, AASHTO T 308 or ASTM D 6307. Advantages of the ignition method include quick results, little testing time, and no solvents are needed. One issue with this method is that in order to obtain an accurate bituminous content for a sample, it is necessary to know the aggregate correction factor. For virgin materials, the aggregate-correction factor is determined by testing samples with a known bitumen content. The difference between the known bitumen content and the test result for the prepared samples is the aggregate-correction factor. However, for RBM, it is not possible to have a sample with a known bitumen content and, therefore, not possible to determine the aggregate-correction factor. Fortunately, aggregate-correction factors are typically consistent over time when the aggregate materials used at the location are from the same quarry or deposits. Therefore, a historical average aggregate correction factor of the materials at a location can be used as the aggregate correction factor for the RBM.

RBM aggregates recovered from the ignition method can be used for gradation analysis and some other aggregate-property tests, but not all. Some aggregate types (e.g., dolomites) can have significant changes in mass when heated to 1000°F in an ignition oven. Small natural variations in the mineralogy of these aggregates create large variations in aggregate-correction factors in the ignition oven (as high as 1% to 2%). Some agencies have altered the test to reduce the ignition oven temperature to minimize this problem. However, in some cases, agencies have elected simply to use other methods for determining bitumen contents and recovering aggregates for bitumen mixes in their jurisdiction. In these locations, the bitumen content for RBM samples should be determined using solvent extractions.

Solvent Extraction

Solvent extractions with trichloroethylene or other solvents have been used for many decades to determine bitumen contents of bitumen mixtures and as a method of recovering aggregates for additional tests. However, use of the method has declined due to health and environmental concerns with the chlorinated solvents. Normal-propylene bromide and some non-halogenated (terpene or d-limonene based) solvents were found to be acceptable alternative solvents and are permitted in AASHTO T 164, but some problems were reported with the effectiveness of these solvents to remove polymer-modified bitumen binders. However, some agencies and contractors continue to use solvent extractions due to problems with highly variable ignition furnace aggregate correction factors or with the breakdown of certain aggregate types. Depending on aggregate characteristics, solvency power of the solvent, and hardness of the binder, solvent extractions may not remove all of the absorbed bitumen binder from the aggregate. Based on the published precision information, the repeatability and reproducibility of the ignition method are more than four times better than the solvent extraction method.

Aggregate Bulk Specific Gravity

An alternate approach to estimating the bulk specific gravity of the RBM aggregate discussed in NCHRP Report 452 (6) was also evaluated in the UNRNCAT study. This approach begins with conducting the maximum theoretical specific gravity tests (i.e., the Rice method) on samples of the RBM following AASHTO T 209. The effective specific gravity of the RBM aggregate is then calculated from the bitumen content and G_{mm} values determined from tests on the samples as follows.

$$G_{se(RAP)} = \frac{100 - P_{b(RAP)}}{\dfrac{100}{G_{mm(RAP)}} - \dfrac{P_{b(RAP)}}{G_b}}$$

The final step is to calculate the RBM aggregate bulk specific gravity using the formula:

$$G_{sb(RAP)} = \frac{G_{se(RAP)}}{\dfrac{P_{ba} \times G_{se(RAP)}}{100 \times G_b} + 1}$$

where P_{ba} (bitumen absorption) and G_b (binder specific gravity) have to be assumed. Historical values for P_{ba} and G_b for the materials used at each plant location should be reviewed to determine if they have been consistent over time.

Advantages of this approach are that no solvent is needed (if the ignition method is used to determine the RBM binder content), and the method is much faster than recovering the RBM aggregate from the solvent extraction or ignition method and testing the aggregate specific gravities using AASHTO T84 and T85, like any other aggregate. However, the accuracy of this method is highly dependent on how well the percentage of absorbed bitumen can be estimated.

Due to the advantages, disadvantages, and limitations of the different methods for determining bitumen contents, recovering RBM aggregates, and determining their properties, it is necessary to have a couple options for testing. It is prudent for agencies and contractors to cooperate in establishing the best methods for the materials in their region or jurisdiction. The following flow charts present two reasonable approaches.

All test results should be recorded in a spreadsheet or software program to organize and summarize the data. The database should include stockpile name/description, date of samples, and for each sample, the results for bitumen content, gradation of recovered aggregate, and bulk specific gravity of the RBM aggregate. The spreadsheet should calculate the average and standard deviation of each property. It is necessary to collect and analyze test results of at least 10 RBM samples to estimate the statistics for the stockpile.

If more RBM is added to the stockpile, sampling and testing should continue at a frequency of one set of tests per 1,000 tons of RBM. Table 2 shows guidelines for standard deviations of key properties of RBM. The standard deviation statistic is a basic measure of variability. The median sieve is the sieve closest to having an average of 50% passing. Typically, this is the sieve with the largest standard deviation. In the example spreadsheet above, the median sieve is the 2.36 mm sieve.

These values are based on data gathered from contractors using many of the best practices in this document. Although excellent RBM-management practices are necessary to have standard deviations within these limits, published reports and recent surveys show indicate that they are attainable. If the variability of one or more properties exceeds the values in Table 2, the stockpile management guidelines in this document may be helpful in reducing the standard deviations. Also keep in mind that sampling practices can have a significant effect on variability results.

Table 2. Variability Guidelines for RBM Stockpiles

RAP Property	Maximum Std. Dev. (%)
Asphalt Content	0.5
% Passing Median Sieve	5.0
% Passing 0.075 mm Sieve	1.0

Annex 2

LIST OF SOME PROJECTS ON RECYCLING CARRIED OUT IN INDIA

1. The main carriageway section of Tumkur – Honnavar Highway, NH-206 near Tumkur strengthened by Full Depth Reclamation (FDR) Technology with a Commercial Cementitious Stabilizer. The pavement section is able to withstand heavy traffic. FWD tests was done to verify design modulus and GPR test was done to check the uniformity & crack formation in cementitious layer.

2. The one side carriageway of Bangalore University in front of Civil Engineering Department was strengthened by Cold Recycling Technology with a Commercial Cementitious Stabilizer. The pavement section is able to withstand heavy traffic in the night time as the road is connecting two major roads approaching Bangalore city. The stretch was evaluated for roughness & stiffness by MERLIN & Geo-gauge respectively.

3. Chennai Tada NH 5 Section total of 12 km with width of 8.75 m.

4. Baroda Halol phase 1 total length of 11 km recycled to a depth of 20 cm.

5. Baroda Halol Phase 2 the total section of 6 km was executed to a depth of 16 cm with foam bitumen as binder.

6. Ahmedabad Mehsana 6 km of cold recycling to a depth of 160 mm under rehabilitation by cold recycling using foam bitumen as binder.

7. Hot in-situ recycling of Mehrauli to Badarpur under Delhi PWD.

8. Recycling of roads in Delhi under Delhi PWD.

REFERENCES

1. NCHRP Synthesis Report 421.
2. FHWA cold in place recycling.
3. Basic Recycling Manual
4. Hot Mix Recycling Document South Africa
5. An Overview of Recycling and Reclamation Methods for Asphalt Pavement
6. Rehabilitation, Asphalt Recycling and Reclaiming Association, Annapolis, MD, 1992.
7. Guideline Specifications for Cold Planing, Asphalt Recycling and Reclaiming Association, Annapolis, MD, 1992.
8. J.D. Brock. Milling and Recycling, Technical Paper T-127. A Industries,
9. Pavement Recycling Guidelines for Local Governments - Reference Manual, Report No.FHWA-TS-87-230, FHWA, U.S. Department of Transportation, Washington, DC, 1987.
10. Proven Guidelines for Hot-Mix Recycling Asphalt Recycling and Reclaiming Association, Annapolis, MD, 1986.
11. Asphalt Hot-Mix Recycling, The Asphalt Institute Manual Series No. 20 (MS-20), Second Edition, 1986.
12. Recycling Hot Mix Asphalt Pavements, Information Series 123, National Asphalt Pavement Association, 1996.
13. D.A. Bernard and J.A. Epps. Pavement Recycling, Prepared for Japan Highway Public Corporation, 1982.
14. V.P. Servas. Asphalt Recycling - The State of the Art, 1980, Report prepared under the joint sponsorship of the United Kingdom Department of Transport, Colas (UK) Ltd. and Shell International Petroleum Co. Ltd., London, 1980.
15. L. Flynn. “Surface Courses in Montana Now May Contain 25% RAP.” Roads and Bridges, October, 1995
16. F.L. Roberts, P.S. Kandhal, E.R. Brown, D. Lee, and T.W. Kennedy. Hot Mix Asphalt Materials, Mixture Design and Construction, Second Edition, NAPA Education Foundation, Lanham, MD, 1996.
17. E.R Brown, N.E. Murphy, and S. Mager. Historical Development of Asphalt Content Determination by the Ignition Method, Proceedings of AAPT, Vol. 64, 1995.

18. J.A. D'Angelo and T. Ferragut. Summary of Simulation Studies from Demonstration Project No. 74: Field Management of Asphalt Mixes, Proceedings of AAPT, Vol. 60, 1991.

19. P.S. Kandhal, K.Y. Foo, and J.A. D'Angelo. Field Management of Hot Mix Asphalt Volumetric Properties, ASTM Special Technical Publication 1299, 1996.

20. Evaluation of Long-Term Field Performance of Cold In-Place Recycled Roads: Field and Laboratory Testing Final Report May 2007, Sponsored by the Iowa Highway Research Board (IHRB Project TR-502) and the Iowa Department of Transportation (CTRE Project 03-160)

21. Draft Report on " Eco Friendly Road Technology using Natural Soil Stabilizer" submitted to the Ministry of Environment & Forests.

(The amendments to this document will be published in its periodical, 'Indian Highways' which shall be considered as effective and as part of the code/guidelines/manual, etc. from the date specified therein)