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GUIDELINES FOR GAP GRADED WEARING COURSE WITH RUBBERISED BITUMEN (BITUMEN-RUBBER)

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GUIDELINES FOR GAP GRADED WEARING COURSE WITH RUBBERISED BITUMEN (BITUMEN-RUBBER)

1 INTRODUCTION

1.1 The draft "Guidelines for Gap Graded Wearing Course with Rubberised Bitumen (Bitumen-Rubber)" was prepared by the Flexible Pavement Committee (H-2) of IRC. The H2 Committee deliberated on the draft in a series of meetings. The H-2 Committee finally, approved the draft document in its meeting held on 3rd January, 2015. The Highways Specifications & Standards Committee (HSS) approved the draft document in its meeting held on 12th January, 2015. The Council in its 204th meeting held at Bhubaneshwar (Odisha) approved the draft Guidelines for Gap Graded Wearing Course with Rubberised Bitumen (Bitumen-Rubber) after taking on board the comments offered by the members.

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1.2 Research and legislation* on using Crumb Rubber (CR) from discarded tyres in bituminous construction particularly in the USA has culminated into the development of technologies (12, 13, 14, 16, 20) and specifications (1, 2, 3, 4) thanks to the concerted efforts and support of highway administration, environmental agencies, research organizations, manufacturers and contracting agencies. The technology known as Asphalt Rubber (AR) technology in the USA, exploits the potential of rubber to greatly improve the properties of bituminous binders, hence that of the bituminous mixes, to enhance eventually the performance of the pavements in terms of strength, durability, serviceability, safety and traffic noise reduction. The driving force behind the technology is the environmental concern for safe disposal of huge pile of discarded tyres of automobiles, which cannot easily be recycled into usable rubber. Its use for industrial applications by burning emits Green House Gases and thereby contributes to global warming and climate change. The AR technology uses rubber from the discarded tyres by converting it into crumbs (of sizes less than 2 mm) to be mixed with bitumen to produce bitumen rubber binder replacing the bitumen only binder.

1.3 Gap Graded mixes with a Bitumen-Rubber (BR) binder (or rubberised bitumen binder) is being successfully used on high volume and other roads of many states of USA to obtain a durable wearing course as well as other countries like Sweden (21), South Africa and China (19). Bitumen-Rubber binder consists of a blend of hot bitumen and crumb rubber (CR) made from scrap or waste tyres. High viscosity bitumen-rubber binder with a minimum crumb rubber contents of 20% by weight of bitumen having a minimum viscosity of 1500 CP at 177ºC is used to obtain the Bitumen Rubber mixes which are resistant to rutting and fatigue fracture along with reduced ageing due to (i) larger binder film thickness and (ii) carbon black in the crumb rubber which imparts resistant to ultraviolet rays trial sections of gap graded bitumen-rubber mixes laid on six lane heavily trafficked National Highways in West Bengal, Maharashtra and Tamilnadu (ref Annex I) have been performing well. Apart from a long life of over ten years as reported from abroad, a special feature of such a wearing course is noticeably reduced noise due to tyre-pavement interaction.

1.4 In India, research has been done to validate some of the important characteristics of the R-B mixes such as viscosity and fatigue life in the laboratory as reported in the international

* (ISTEA- Intermodal SurfaceTransportation Efficiency Act of 1991 passed by the US Congress)

specifications and three experimental stretches were laid 12 to 24 months ago in different parts of the country. These studies show great promise of this technology. Notwithstanding the limitation of Indian experience with the technology, these Guidelines recommend its full scale implementation for the following five reasons:

(a) It uses wastes and helps their safe disposal without GHG emission while enhancing the performance of bituminous pavements;

(b) The theoretical basis of the technology is sound and is well understood;

(c) The research and field experience elsewhere is enormous and very positive;

(d) Use of this useful technology would require only minor capital investment; and

(e) These Guidelines would create an enabling environment for these efforts.

1.5 An overview of the Bitumen Rubber or Rubberised Bitumen (RB) technology is presented in Annex I.

2 SCOPE

These Guidelines cover construction of a single layer of gap graded wearing course of thickness 40 to 50 mm, using wet hot mix process for mix production and ambient grinding for granulating the used tyres (ref Annex I), to be laid over

(i) a newly constructed bituminous layer, or

(ii) an old bituminous layer as a reflection-crack resistant durable overlay.

3 MATERIALS

3.1 Crumb Rubber

Crumb Rubber (CR) obtained from discarded tyres[1] of automobiles are commonly used for blending with bitumen. Wire in CR must be less than 0.01% and the fabric should be less than 0.95%. The gradation of crumb rubber for blending with bitumen is shown in **Table 1**. The quantity of Crumb Rubber (CR)[2] required to obtain the required viscosity may vary and can be 20% or higher but in no case it should be less than 15%.

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[1] California requires rubber from tyres and that from other high natural rubber (40 to 48%) wastes in 75:25 ratio for production of Asphalt Rubber while other States do not specify such requirements. Insistence on natural rubber apparently is because car tyres may be deficient in natural rubber as the manufacturers of car tyres abroad use more synthetic rubber than natural rubber to economise on cost. Vulcanized natural rubber gives better elastic recovery and is good for rubberized Bitumen. Indian car tyres use high percentage (nearly 44%) of natural rubber in car tyres and therefore, crumb rubber produced from both car and truck tyres are considered suitable. The test for the quality of the rubberised binder as determined from viscosity and elastic recovery test, in any case would establish the suitability of CR.

[2] It depends upon the fineness of the rubber particles. Finer the rubber particles, lower is the quantity of crumb rubber needed to obtain the required viscosity shown in **Table 2**. A number of gradations included in the specifications of many Departments of Transportation of USA are given in Annexure I.

Table 1 Gradation of Crumb Rubber

Sieve Size, mm	% Passing
1.18	100
0.6	90-100
0.425	45-100

Specific gravity of crumb rubber should be between 1.10 and 1.12. The CR ground and granulated at ambient temperature shall be used.

3.2 Base Bitumen

Base bitumen which will be blended with CR shall be (a) VG 30 where pavements are likely to carry a traffic of 30 msa or higher in fifteen years exceeds 30ºC, and (b) VG 10 where traffic is less than 30 msa and the maximum ambient temperature is less than 30ºC.

3.3 Aggregates

3.3.1 Aggregates gradation and their physical requirements shall be as per **Tables 2 and 3**.

Table 2 Gradations of Gap Graded Aggtegates

Sive Size, mm	% Passing
19	100
13.2	80-100
9.5	65-80
4.75	28-42
2.36	14-22
.075	0-2.5

Table 3 Physical Requirement of Aggregates

Property	Test	Method	Specification
Cleanliness	Grain size analysis test	IS: 2386 (P-1)	< 2% passing 0.075 mm sieve
Partcile Shape	Combined Flakiness and Elongation Index	IS: 2386 (P-1)	<30%
Strength	Los Angeles Abrasion Value	IS:2386 (P-4)	<25%
	Aggregate Impact Value	IS: 2386 (P-4)	<18%
Polishing*	Polished stone value	IS: 2386 (P-114)	>55%
Durability	Soundness (either Sodium or Magnesium) – 5 cycles		
	Sodium Sulphate	IS: 2386 (P-4)	<12%
	Magnesium Sulphate	IS: 2386 (P-4)	<18%
Water Absorption	Water Absorption	IS: 2386 (P-3)	<2%

Note: The fine aggregates shall meet the properties as per IRC:111-2009.

4. BLENDING OF BITUMEN-RUBBER

Crumb Rubber shall be blended with base bitumen to produce the Rubberised Bitumen (RB) binder to be used in the hot mix plant instead of only base bituminous binder. This shall be achieved in two stages, viz. mixing stage and reaction stage in two separate chambers under controlled conditions when high production rate is required. The temperature of the bitumen shall be 190ºC at the time of addition of the ground rubber. There is a drop in temperature of the bitumen when crumb rubber at the ambient temperature is added to the binder. No agglomerations of rubber particles shall be allowed into the mixing chamber. Calcium carbonate powder may be added to the crumb rubber to ensure a free flow condition. The rubber shall be sufficiently dry to be free flowing and not produce a foaming problem when added to hot bitumen.

The ground rubber and bitumen shall be accurately proportioned in accordance with the design and thoroughly mixed prior to the beginning of the reaction for one hour duration in the reaction vessel. The proportions of base bitumen and the crumb rubber shall be accurately controlled and documented. Methods shall be devised to ensure that the rubber has been uniformly incorporated into the mixture and that the rubber particles have been thoroughly mixed and "wetted." The occurrence of rubber floating on the surface or agglomerations of rubber particles shall be evidence of insufficient mixing. **Fig. 1** shows a schematic diagram of the blending process.

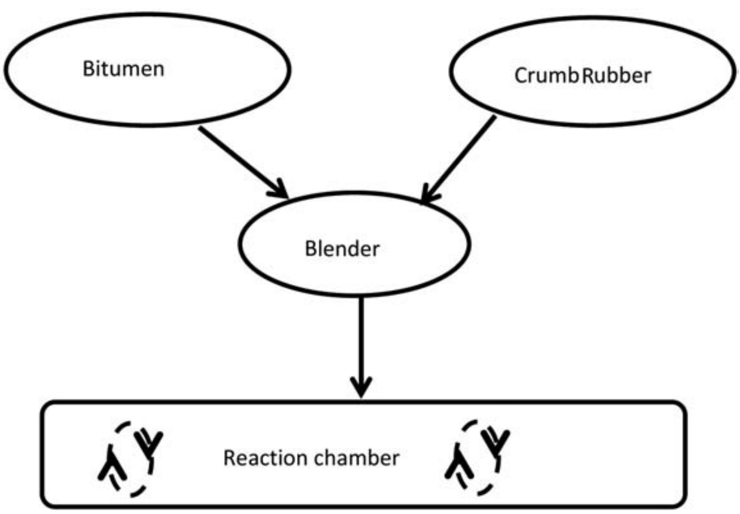

Fig. 1 Bitumen-Rubber Binder Production Process

Once the bitumen-rubber has been mixed, it is pumped to a reaction tank where a temperature of 190ºC shall be maintained with agitation for 60 minutes for a proper blending. After the reaction, the Bitumen-Rubber binder shall be maintained at 180ºC to 190ºC before its introduction to hot mix plant. Pumping is difficult at lower temperatures. However, in no case shall the bitumen-rubber binder be held at a temperature of 160ºC or above for more than 10 hours. If the bitumen-rubber binder is to be stored for longer hours, it shall be allowed to cool down to 130ºC to 140ºC and gradually reheated to a temperature between 180ºC and 190ºC with agitation before use. Only one cooling and one reheating shall be allowed. Bitumen-rubber binder shall not be held at temperatures of 130ºC to 140ºC for more than four days. Prior to use, the viscosity of the asphalt-rubber shall be tested by the use of a rotational viscometer **(AASHTO T 316 and ASTM D 4402: Viscosity Determination of Asphalt Binder Using Rotational Viscometer)**. Bitumen-rubber binder shall conform to the **Table 4**. The binder temperature at the time of mixing should be 170ºC to 185ºC.

Table 4 Properties of Bitumen-Rubber Binder

Property	Requirement
Base bitumen	VG 30 for traffic > 30 msa and maximum air temperature ≥ 30ºC VG 10 for pavement temperature ≤ 30ºC
Viscosity at 177ºC by rotational viscometer (Brookfield), Centipoise	1500-4000
Softening point	≥ 60ºC
Elastic Recovery as per the test method of IRC:SP:53-2010	≥ 60
Storage stability	This is not necessary for site blending and immediate use. Otherwise storage stability criterion as per IRC:SP:53-2010 shall be adopted

Note : Crumb rubber absorbs the lighter fractions of bitumen and, therefore, if solvent method is used for determination of binder content in any mix post construction, the test is likely to underestimate the binder content. More accurate determination of binder content can be made only by ignition tests.

5. PUMPING OF RB BINDER INTO HOT MIX PLANT

Highly viscous nature of the RB binder would not permit the binder to be pumped into the hot mix plant if the temperature is lower than 180ºC with the help of the usual pumping system of the hot mix plants.

6. MIX DESIGN CRITERIA

Corelok (AASHTO TP 69: Bulk Specific Gravity and Density of Compacted Asphalt Mixtures Using Automatic Vacuum Sealing Method) or paraffin coating method (AASHTO T 275) should be used for determining air voids and voids in mineral aggregates (Water entering into the air voids in the interior of gap or open graded compacted samples while weighing in water leads to serious errors in estimating the air voids and voids in Mineral Aggregates. Paraffin coating by dipping the Marshall specimens in molten paraffin gives reasonably good results).

The mix design criteria are shown in **Table 5.**

Table 5 Mix Design Requirement of Gap Graded Bitumen-Rubber Mix (Compacted Thickness 40 mm to 50 mm)

Property	Requirement	Remarks
Marshall Stability	5.40 kN[3]	Usually, there is no stability requirement for gap graded mixes.
Percent air void	4-6	
Voids in Mineral aggregates	Min 19%	
Compaction Number of blows per face	75	Los Angles Abrasion value aggregate should be less than 25 to control degradation during construction
Bitumen drain down test, AASHTO T305	Mix 0.3%	(Annexure C of IRC:SP:79-2008)
Tensile Strength Ratio (TSR) as per AASHTO-T 283	85 min	(Annexure D of IRC:SP:79-2008)
Bitumen-rubber binder, Percent	7 Min	The optimum binder content can vary depending upon the surface texture and specific gravity of aggregates

Mix design for the gap graded RB mix should be carried out at binder contents of 6.5%, 7.5% and 8.5% and the Optimum binder content should be evaluated at 5% air void. Such mixes are highly rut resistant due to the stiff binder and stone to stone contact.

7. MIXING AND LAYING

7.1 IRC-MORTH Guidelines and Specifications shall be applicable to the construction and quality assurance of wearing course using RB binder. The temperature of mixing shall be between 160ºC and 170ºC. The compaction temperature of the mix shall lie between 140ºC and 150ºC.Warm mix additives can be used to obtain lower mixing and compaction temperatures (8, 9, 10, 11). The B-R mix should not be laid over a cracked bituminous or concrete pavements(7)having cracks as wide as 12.5 mm wide. SAMI using CRMB/PMB meeting the MORTH specifications should always be used when laying over a cracked pavement.

8. WEATHER LIMITATIONS

Laying of RB mix should be done only when the air temperature is above 15ºC because of compaction problem at lower temperatures or when the wind speed exceeds 40 km per hour at a height of 2 m.Rainy weather should be avoided.

9. SPREADING:

The RB mix shall be spread, levelled and tamped byself-propelled paving machine.

[3] A minimum value of 5.4 kN (1200lb) has been adopted by designers as per published reports

10. ROLLING

a. Rolling should commence immediately after laying of the mix. pneumatic tyred compactor shall not be used to eliminate possible picking of the B-R mix. Only steel wheel roller should be used. Rolling method as prescribed in MORTH shall be used.

b. The maximum air void after the compaction shall be 8 percent.

c. Three steel wheel tandem rollers should be used for faster compaction due to rapid cooling of thin wearing course.

11. APPLICATION OF BLOTTER MATERIAL

Bitumen-Rubber mix may be picked up the pneumatic tyres of vehicles and hence it is necessary to apply sand @ I kg/m^2 before opening the road to traffic.

12. USE OF GAP GRADED B-R MIX

The bitumen-rubber mix can be used wherever conventional bituminous concrete (BC) would be used, but it provides better resistance to reflective cracking and fatigue fracture than the standard dense-graded bituminous concrete. Bitumen rubber hot mixes are typically most effective as thin rehabilitative overlays of distressed flexible or rigid pavements. The thickness equivalency of dense graded BC and gap graded B-R mix for resistance against reflection cracking has been well-documented (5) by CALTRANS. Laboratory tests at IIT Kharagpur (6) on different mixes (refer Table in para 14/Annex I) clearly indicate that the gap graded mixes have significantly higher fatigue lives than the dense graded BC. This explains the findings of CALTRANS (5) also. These Guidelines, however, do not recommend any reduction in design thickness based on equivalency factors.

13. QUALITY ASSURANCE

13.1 Crumb rubber source shall be selected in a manner that the material produced is in the desired quantity and of uniform quality.

13.2 Crumb rubber production plants shall be equipped with capabilities of shredding the tyres; successive size reductions by tearing, shearing, grinding, granulation; separation of steel and fibre by magnetic and cyclonic facilities respectively; appropriate controls (hydraulic/mechanical/electrical/electronic as appropriate) for material feed, conveyance to various units, size fractions of outputs; collection, packaging and storage of the product.

13.3 Depending upon the mode of mixing and blending of the crumb rubber with bitumen as well as production of hot mix (batch or continuous), the rate of inflow to various units of production, i.e. the mixing chamber, reaction chamber and hot mix plants, shall be synchronised to achieve the desired rate of output without any hold up or disruption in the production process.

13.4 Flow of materials (CR, Base bitumen, RB binder) into various units shall be measured by mass meters, which should be electronically controlled and set for ensuring right proportions and quantities as per the requirements of these Guidelines.

13.5 Heat transfer and temperature control in bitumen storage tank, mixing chamber, reaction chamber and hot mix plant shall be thermostatic and set electronically.

13.6 The rate of agitation and the time required for mixing in the mixing and reaction chambers as well as hot mix plants shall be arrived at after trial runs and set electronically after successful trials.

13.7 All equipment and components shall be calibrated and recalibrated to ensure uniform quality spatially as well as temporally. All equipment settings shall be decided after successful trial runs and documented. All equipment and plant operation shall be supervised by experienced personnel and checks shall be exercised at every step before undertaking the next step of operation.

13.8 All input materials, processes and outputs shall be document with regard to the specific control parameters like mass, temperature, mixing/blending, viscosity, etc., as relevant and required as per these Guidelines.

Annex - I

AN OVERVIEW OF RUBBERISED BITUMEN TECHNOLOGY

1. Use of rubber with bitumen to produce a different binder (wet process) or in replacement of certain finer fractions of mineral aggregates with unaltered bituminous binder (dry process) for application in bituminous construction is known by the name 'Asphalt-Rubber' (AR) in the USA and by other names elsewhere in the world e.g. the Recycled Tyre Rubber Modified Bitumen (RTR-MB), Bitumen-Rubber-Asphalt (BRA), Rubberized Bitumen, etc. This document deals with wet process and name given to the rubber modified binder is "Rubberised Bitumen" to distinguish it from the normal bituminous binder as well as other "Modified Bituminous binders" such as "Crumb Rubber Modified Binder (CRMB)" or "Polymer Modified Binder (PMB)". Since the technology has evolved with reference to "Asphalt Rubber" no attempt has been made in this Annex to change the name while presenting the technology overview. "Rubberised Bitumen" referred to in the main document should be considered synonymous with "Asphalt Rubber in wet process".

2. HISTORICAL PERSPECTIVE

2.1 The Asphalt-Rubber technology has established itself by now even though its first application was recorded more than half a century ago in 1960. Charles McDonald, a material engineer of city of Phoenix in Arizona found that after mixing RTR with hot bitumen and allowing it to react for 45 minutes, the product (which McDonald patented as Asphalt Rubber) captured the beneficial engineering characteristics of both the base ingredients [Lo Prestie, 2013]. The early application of AR was in the form of prefabricated patching of the cracked surfaces, which was called "band aids", followed by its application in full width in slurry seal application with cover chips in the seventies. The latter application was not found very successful because of non-uniform thickness of slurry seal because of the irregularity in the surface profile [RPA]. In the sixties experiments with natural rubber were also carried out and reported by Federal Highway Administration though with inconclusive results [RPA]. Around same time when McDonald developed the wet process, Swedish companies developed the dry process by substituting certain aggregate fractions by crumb rubber to tackle the problem of deterioration of pavement by studded tyres. The early development in AR was mostly marked by trial and error.

2.2 The real boost to this technology came in the late eighties and early nineties thanks to various developments, three of which are worth noting. First, in 1988, ASTM gave a formal definition of Asphalt Rubber (ASTM D18) and subsequently prescribed specifications for it (ASTM D 6114) in 1997. Secondly, the patent of McDonald expired in 1992 and the product came in public domain enabling more generic use and applications. Thirdly, a US Federal Law passed in 1991 "Intermodal Surface Transportation Efficiency Act" (ISTEA) mandated widespread use of Asphalt-Rubber technology. Since then considerable interest was generated in research and development efforts, which were sponsored mainly by four states of the USA, viz., Arizona, California, Texas and Florida as well as Federal Highway Administration. Reputed Universities like Arizona State University, University of California Berkley, big private companies and California integrated Waste management Board also participated, sponsored or supported the research efforts. Since late nineties till 2009 a number of International Conferences and Seminars were held in different parts of the World (USA, Portugal, Brazil, China). These research reports are synthesised in NCHRP reports and SHRP reports. Rubber Pavement Association also documents the research efforts in various forms.

2.3 The current status of the AR technology is that there are specifications for AR prescribed by ASTM and these are followed by the states in USA. Apart from the four pioneer states, other states such as South Carolina, Nevada and New Mexico have also joined the AR bandwagon. AR technology is in use in South Africa, which uses both wet and dry process. Australia uses this technology mostly in spray application for crack sealing and chip seal. In Europe, the wet process is reportedly being followed since nineteen eighties in Belgium, France, Austria, Netherlands, Poland and Germany, and more recently in Greece and UK, but the countries with a higher number of applications are reportedly Portugal, Spain, Italy, Czech Republic and Sweden. Latest entrants to the AR user group are China, Brazil, Taiwan, and Sudan [Lo Prestie]. The ASTM specifications almost set the benchmark for specifications in other countries. For example the South African Bitumen Association (SABITA) Manual 19 dealing with AR is based on these specifications and research is directed to revise and improve the manual by further research.

3. THE DRIVING FORCE FOR AR TECHNOLOGY

3.1 The driving force behind the used tyre rubbers in bituminous construction are mainly two; one, the social responsibility of safe disposal of used tyres without creating any environmental problems, and second exploiting the potential of the tyre ingredients to enhance the performance of bituminous construction in terms of strength, durability, serviceability and eventually cost efficiency in terms of reduced life cycle cost.

i) **Environmentally Safe disposal of used tyres:** Basically three steps are involved in safe disposal of any waste, viz. (a) recycling the wastes by extracting the useful materials and re-using in further production, (b) extracting the energy from the wastes and using the residue for productive purposes (c) dumping the residues and the wastes into landfills after material and energy are extracted. Waste tyres contain lot of useful materials (rubber, steel, fabric, carbon black) each of which can be extracted, but the main ingredient, the tyre rubber, cannot be recycled for use in further production of rubber. Safe energy extraction (as opposed to open burning and release of Green House Gases in the atmosphere) involves sophisticated processes like pyrolysis which are highly expensive. That leaves only two options for disposal of waste tyres, viz. dumping in landfills or burning, neither of which is environmentally safe.

ii) **Exploiting the potential of the extracted rubber in bituminous construction:** Research has established that the extracted rubber when converted into crumbs, if mixed and blended with bitumen under controlled conditions, can drastically improve the binder properties and give the bituminous pavements more strength, durability, serviceability, riding comfort and noise reduction. The rubber should, therefore, be used with bitumen to enhance the performance of the bituminous pavements.

3.2 The synergy of the two forces have resulted in extensive research in the field of (a) rubber bitumen interaction (both in laboratory and field), (b) development of technologies for recovery of useful materials from used tyres, (c) creation of manufacturing capacity for producing value out of wastes, and (d) emergence of niche markets for such products. There are numerous companies in USA and Europe which 'manufacture' and supply crumb rubber in various sizes, shapes and colours to meet the users' demands, or provide technology solutions for use of such wastes.

4. CONSTITUENTS OF TYRES: RUBBER, CARBON BLACK, STEEL, FIBRES

The components of tyre are air impervious inner liner; steel belt, nylon belt, body plies calendared over the outer surface of the inner liner to withstand the air pressure; patterned treads also a calendared rubber sheet, to provide grip; sidewalls to additionally resist weathering action; triangular portion with steel beading to fit into the tyre rim; some rubber, glue or resin fillings to cushion the plies and treads from wear and tear from abrasion from belts. Materials used in tyre manufacture are elastomers (natural and synthetic rubber), carbon black, steel and fabric each of which performs different functions. Natural rubber (poly-isoprene) acquires elastic properties due to the process of vulcanisation, while synthetic rubber (styrene-butadiene and halo-butadiene) is already hard and elastic. Carbon black provides reinforcement to tyres, silica adds heat resistance to tyres, some anti-oxidants give weather resistance to tyre walls. In addition, there are some chemicals like sulphur, activator, accelerators and curing compounds, which take part in vulcanising process.

5. SCRAP TYRE PRODUCTS: CRUMB RUBBER COMPRISING RUBBER AND CARBON BLACK

One research [Wrap] indicates that when the car tyre is ground, nearly 70% of it gets converted into crumb rubber and 17% of steel, 13% of fibre and scrap are isolated. The crumb rubber consists of both natural and synthetic rubber as well as carbon black. Another study [RPA] also corroborates 70% of tyre component comprising rubber (natural and synthetic) and carbon black. The latter study further indicates the proportion of natural rubber, synthetic rubber and carbon black as 15%, 27% and 28% respectively. The trend abroad in car tyre production is to supplement the rubber requirement by synthetic rubber for economising on the raw material cost, natural rubber being costlier than the synthetic rubber. Indian car tyres, on the other hand, have a much higher (nearly 44%) of natural rubber.

6. SCRAP CAR TYRES MAY NOT CONTAIN SUFFICIENT NATURAL RUBBER, MAY NEED TO BE SUPPLEMENTED

As discussed in the para above car tyres may be deficient in natural rubber content. That perhaps explains the provisions in the CALTARN Guidelines. The Guidelines while specifying various Crumb Rubber Modifiers (CRM), specifies the requirements of “High Natural Rubber (Hi nat)” CRM as follows: “scrap rubber product that includes 40-48 per cent natural rubber or isoprene and a minimum of 50 per cent of rubber hydrocarbon…..Sources of high natural rubber include some types of heavy truck tires, but are not limited to scrap tyres…” and further provides that “CRM must include 25±2 per cent by mass of high natural rubber CRM and 75±2 per cent scrap tyre CRM”. This requirement is not specified in any other Specifications of US States. South Africa also specifies 25% of the natural rubber requirement.

7. WHY INSISTENCE ON NATURAL RUBBER IN CR

7.1 The natural rubber is derived from rubber trees and comprises poly-isoprene polymer chain. The rubber is quite sticky (more plastic than elastic) at normal temperature or in warm conditions and becomes brittle when cold. Its long polymer chains move independently of each other because of which it has very little strength. However, when vulcanised, they acquire strength, durability, elasticity and all the desirable engineering, mechanical and chemical properties which, in combination with some other materials like carbon black and silica make them suitable for withstanding the air pressure, abrasion and heat generation. Natural rubber, however, is more susceptible to weathering action due to oxidation and ozonisation. Synthetic rubber on the other hand are derived from petroleum by products and have similar characteristics as natural rubber, or even better (particularly in resistance to oxidation and ozonisation and hence weathering). These are better materials than natural rubber for tyre side walls, which are exposed to weathering action. The synthetic rubber that goes into production of tyres are Styrene-butadiene, Poly-butadiene, Halo-butyle rubber, etc.

7.2 The real difference in the two types of rubbers arises out of the process of vulcanisation, which are different in the two types of rubber. Vulcanisation of natural rubber is done with sulphur by cooking the rubber at 170ºC under pressure for about 10 minutes. The sulphur molecules cross link the polymer chains of the natural rubber building bridges between the chains. These chains, which in un-vulcanised condition could move independently of each other cannot do so after bonding with sulphur on vulcanisation. Vulcanisation agents for synthetic rubber are not sulphur but some metal oxides (MgO, ZnO, PbO) or other chemicals. Sulphur bonds are much stronger than the bonds provided by the latter agents. As a result, vulcanisation of natural rubber is almost an irreversible process and cannot be devulcanised, while the bonds in the synthetic rubber can devulcanise under high temperature and lose their properties. That is why natural rubber in a certain proportion is insisted upon in AR application.

8. ASPHALT RUBBER PROCESSES

There are essentially two types of processes

8.1 Dry Process

In this process certain fractions of mineral aggregates are replaced by crumb rubber and the binder remains the normal bituminous binder. CR is added to the aggregate in hot mix process just before bitumen is fed into the hot mix plants. Dry process remains essentially dense graded construction with some size fraction in grading provided by CR. This process does not appear to be as effective as wet process. The binder coating the CR particles keeps on absorbing the lighter fractions of bitumen like aromatic oils and eventually the effective bitumen content in the mix reduces. Secondly, with some absorption of bitumen by the CR fraction their sizes change and the grading may be upset.

8.2 Wet Process

In this process the bituminous binder properties are altered by addition of crumb rubber to the binder and agitating it for 45 minutes to an hour at high temperature to allow the absorption of aromatic oils there by increasing the viscosity of the binder enabling thicker binder coating of the aggregates. This makes the binder resistant to weathering and oxidation and hence to ageing and cracking. Wet process has two applications, viz., hot mix application with gap-graded aggregates and spray application with open-graded aggregates. In hot mix application, point to point contact between aggregates are ensured while forming a continuous networked matrix of rubber through the binder, which provides rubber-like flexibility to the mix. In open-graded mix the aggregates stick to the binder and each other in a better manner due to stickier viscous binder.

9. ASPHALT RUBBER BINDER (RUBBERISED BITUMEN BINDER)

A formal definition of such binders is provided by ASTM as “a blend of asphalt cement, reclaimed tire rubber, and certain additives in which the rubber component is at least 15 per cent by weight of the total blend and has reacted in hot asphalt cement sufficiently to cause swelling of the rubber particles” (ASTM D8). The Specifications for AR have also been provided by ASTM (ASTM D 6114). The definition underlines the ingredients of such binders (bitumen, tyre rubber and additives), the processes (producing crumb from reclaimed tyres, mixing, blending and reaction in hot condition) and the output (a blend with swollen rubber particles). The definition also sets a floor level for proportion of rubber (15%) in the blend. The additives referred to in the definition are certain ‘extender oils’, which make the rubber bitumen reaction easy. This definition finds almost universal acceptance.

10. INGREDIENTS OF ASPHALT BINDER

10.1 Crumb Rubber (CR):

10.1.1 Most Specifications in the US States prescribe scrap tyres as the CR source, Caltran specifies 75% scrap tyres and 25% high natural rubber modifier, South Africa species scrap tyre rubbers from cars and trucks. In these specifications scrap tyres with minimum 50% natural rubber is proposed.

10.1.2 As regards gradation of crumb rubber all specifications (Arizona, Texas, Florida, California in the USA and South Africa) prescribe maximum particle size finer than 2.36 mm and minimum 75 micron. Majority of them prescribe sizes finer than 1.18 mm. These Guidelines also provide maximum size finer than 1.18 mm and propose median size as 425 micron.

10.1.3 A comparative gradation of CR in the four States of USA is presented in the Table below:

Sieve Size, mm	% Passing			
	Caltrans	Texas	Arizona	Florida
2.00	100		100	-
1.18	95-100	100	65-100	100
0.6	35-88	90-100	20-100	70-100
0.425	-	45-100	-	
0.300	10-30		0-45	20-40
0.15	0-4		-	
0.075	0-1		0-5	

10.1.4 Quantity of CR to be mixed with bitumen subject to minimum of 15% (specified by ASTM) is a matter of design to achieve the target AR binder properties in terms of viscosity, resilience, softening point and cone penetration. Most Guidelines including these Guidelines suggest a trial with 20% CR.

10.2 Bitumen

There is no ASTM recommendation with regard to Base bitumen except that it should be selected on the basis of climatic conditions. Arizona and Texas specify three climatic zones (hot, mild and cold) while Caltran and Florida recommend only one type of base bitumen. South Africa specifies only 'standard penetration grade bitumen' conforming to their national standards and also gives the choice to the supplier to select the base binder. In the USA bitumen is standardised and classified in Performance Grades. The three types of base bitumen recommended in these States correspond to penetration grades 60/70, 85/110 and 120/200. In these Guidelines VG 30 is proposed in general and VG 10 in cold climate.

10.3 Additives

ASTM permits some additives apart from CR and Bitumen to facilitate the reaction between CR and Bitumen. Caltran allows this additive named as Extender Oil, which are "aromatic oils used to promote the reaction of the asphalt cement and the crumb rubber modifier". This is not permitted in the specifications of the other three States, though South Africa permits it. These Guidelines do not provide for any additives or extender oil.

11. PROCESSES FOR PRODUCTION OF ASPHALT RUBBER BINDER (RUBBERIZED BITUMEN BINDER)

11.1 Production of Crumb Rubber

11.1.1 There are essentially two methods of production of Crumb Rubber; viz., Ambient Grinding and Cryogenic Process. In Ambient Grinding the tyres are shredded, sheared, subjected to successive size reduction, grinding and micro grinding (or micro milling) all at ambient temperature. In Cryogenic process, the tyres are frozen in liquid nitrogen, which makes them brittle and then broken and ground into granulates. All specifications recommend Ambient Grinding Process, which is cheaper and gives better size and texture of the crumbs compared to cryogenic grinding, which is hugely expensive. These Guidelines also recommend Ambient Grinding Process for production of Crumb Rubber.

11.1.2 Ambient grinding process involves the following stages:

(i) **Shredding:** Whole or cut tyres are shredded in shredder (called cracker mill), the expected output of shredder is pieces 50 mm in size

(ii) **Granulation:** The shredded output is fed into Primary granulators, where the size reduction is to the extent of 9.5 mm.

(iii) **Primary Steel and Fibre Removal:** Steel and Fibre are removed at this stage. Steel is removed by magnetic separators and fibre by cyclonic separators.

(iv) **Secondary Granulators:** The granulated crumb is passed through successive secondary granulators to further reduce the size. The output of each secondary granulation unit is conveyed to the successive units pneumatically and collected in closed hoppers.

(v) **Secondary Metal and Fibre Separators:** Before final grinding output is collected the metal and fibre has to be separated.

(vi) **Bag House for Dust:** Every granulation stage has to be connected to a dust collector bag house.

11.1.3 Usually crumb rubber is produced off site and procured from crumb rubber manufacturers in damp proof packaging. It is necessary to ensure that the production process followed in its manufacture is Ambient Grinding. The crumb rubber should be tested for moisture content, gradation, fibre and steel contents, and its constituents, mainly the proportion of natural rubber and carbon black before its acceptance and application. It may be necessary to add a small amount of calcium carbonate powder to absorb the moisture and make the crumb free flowing.

11.2 Production of Asphalt Rubber (Rubberised Bitumen)

11.2.1 Production of AR involves two stages, viz., (a) mixing and blending of crumb rubber and base bitumen, and (b) reaction of the mix to enable complete absorption till saturation of the lighter fractions of bitumen, i.e. Asphaltene and aromatic oils.

(a) Before the start of the process, the bitumen has to be heated to 190ºC. The metred quantity of heated bitumen and CR are fed into the mixing and blending chamber to ensure the right proportion. Mixing of crumb rubber at ambient temperature and heated bitumen would cause the temperature to drop. It needs to be ensured that after the temperature drop the mix remains within the temperature range of 170º-185ºC. Metering of bitumen has to be with an electromechanical meter and that of the crumb through a weigh hopper with load cells. Mixing and blending in the chamber will be by a mechanical mixer. The rate of material feed and mixing should be synchronised to produce a homogeneous mix.

(b) The CR-bitumen blend is sent to the Reaction chamber through a meter which would measure the rate of input and its quantity. The Reaction Chamber will have arrangement for heating and agitation. A typical heating arrangement could be a flue tube recirculating hot gases from a burner and agitation arrangement by an auger. The temperature of the blend received in the Reaction Chamber will be in the range of 170-180ºC. This has to be raised to 190ºC and maintained at that temperature and the blend agitated for at least one hour for binder-rubber reaction to be completed. Temperature control should be thermostatic and electronic.

11.2.2 The output of the Reaction Chamber has to be tested for the target viscosity of the AR binder should satisfy the design requirement by a hand held viscometer for its acceptance within tolerances allowed for field and laboratory tests arrived at after trials at site.

11.2.3 The conforming output can be (i) Directly pumped to the hot mix plant, or (ii) stored for not more than 4 hours, or (iii) allowed to cool to a temperature of 135ºC and stored for not more than 4 days provided it is reheated to 190ºC before actual use, only one cycle of cooling and reheating being permitted.

11.2.4 The entire process can be accomplished either in batch mode or continuous mode. In the latter mode all inputs, processes and outputs have to be synchronised to meet the requirements of end use.

11.3 Nature of Reaction

Crumb rubber in the Asphalt Rubber binder absorbs the aromatic oils in bitumen and swells. This process happens even at room temperature, but at an optimum temperature (refer to sub para (b) of the para above), the process of swelling is fastest and maximum resulting in very high viscosity of the binder and consequently very thick film coating of aggregates (18 micron compared to 9 micron in normal bitumen). At cooler temperatures, the crumbs would tend to settle instead of remaining dispersed and in suspension in bitumen. At higher temperatures and/or higher agitation of the mix the crumbs will start depolymerising and devulcanising, as a result of which the beneficial effects of rubber (stiffness, elasticity, etc) would be gone.

12. TARGET PROPERTIES OF RUBBERISED BITUMEN BINDER

CALTARN and other Guidelines suggest four parameters for design and specify the range of values for these parameters, which are: viscosity, elastic recovery, softening point and penetration. These Guidelines have included the first three and omitted penetration, not considering it of much relevance as viscosity itself is sufficient to capture the result of this test.

13. WHY GAP-GRADING

These Guidelines have recommended use of rubberised bitumen binder only with gap graded aggregates. This is for two reasons: (i) Dense grading does not permit enough space to accommodate highly viscous thick binder in the voids. During compaction of the mix the rubber would compress but would immediately decompress after the roller moves out, thus density in compaction cannot be achieved, (ii) In gap grading, there is a point to point contact between aggregate particles and large voids in-between, which are filled with rubberised bitumen. After curing, the rubber under traffic would behave like tyre under pressure, strengthened by the presence of carbon black in the crumb, whose role in the tyre was to reinforce the latter. CALTARN, accordingly proposes higher equivalencies to such mixes compared to the conventional dense graded mixes. The Table below presents the thickness equivalencies:

Thickness of Dense Graded BC, mm	Thickness of GG B-R Mix for Equal Resistance Against Reflection Cracking with SAMI
45	30
60	30
75	45
90	45
100	60
120	60

14. INDIAN STUDIES ON GAP-GRADED RUBBERISED BITUMEN BINDER

India so far is nowhere in the World map of Asphalt Rubber User countries. Very limited studies have been reported either from field or laboratories. Interest has generated on the subject only very recently. An IIT, Kharagpur laboratory study reported in 2014 corroborates that Viscosity of the Asphalt rubber binder is possible to be attained in the range of 1500-4000 cP and that, compared to dense graded bituminous mixes using modified binders, can have more than 3 to 5 times fatigue life even at a very high, 400 micro strain, compared to dense graded mixes (See Table below).

Fatigue Test on dense graded and gap graded bituminous mixes (6)

Mix	Binder	Fatigue Life at 400 Microstrain In Beam Fatigue
Dense graded BC	VG30	15350
	CRMB	24860
	PMB	35325
Gap graded mixes with	Crumb rubber modified bitumen	>100000
polymer and crumb rubber modified mixes	Polymer modified bitumen	>100000
	Polymer modified bitumen II	>100000

Even at 1000 micro strain, gap graded bitumen-rubber mix has a fatigue life over 100,000 repetitions. These studies are not in the nature of a revelation but only a validation of what is already known and applied in AR technology user countries (e.g. thickness equivalency factors of CALTARN referred to above). As for field application, three trial stretches, one each on NH 3 (Nashik-Gonde) in Maharashtra, on NH 46 (Krishnagiri-Walajahpet) in Tamil Nadu and on NH 6 (near Uluberia) in West Bengal were laid less than 2 years ago and are not showing any signs of rutting so far even though these are arterial national routes and carry very heavy traffic.

15. ADVANTAGES OF BITUMEN RUBBER TECHNOLOGY

Bituminous Rubber and bitumen-Rubber mix have the following advantages

1. Increased viscosity of the B-R binder allows higher film thickness with little drain down
2. Reduced temperature susceptibility
3. Improved resistance to rutting due to higher binder viscosity and stone to stone contact of coarser aggregates
4. Good durability due to better resistance to cracking and ageing
5. Reduced noise due to vehicle –tyre interaction
6. Environmentally friendly since it makes use of waste material
7. Can be laid over cracked bituminous layer because of better resistance to reflection cracking. It is suitable for concrete pavements also with added advantage of noise reduction and improved riding quality
8. Cost effective since a lower thickness of Bitumen-Rubber mix is needed than a conventional bituminous concrete for the same performance from crack propagation. For equal thickness, life cycle cost is likely to be much lower than the conventional dense graded Bituminous Concrete.

16. SOME INCONVENIENT QUESTIONS WITH REGARD TO USE OF THE TECHNOLOGY

16.1 Recyclability of the Mix

A 1992 study (18) raises questions about recyclability of the mix, which might have to be dumped as waste creating more environmental problem than it would solve. The CALTARN Usage Guide of 2006 (12) discounts this fear, though admits that air quality during recycling might be of some concern.

16.2 Higher Initial Costs

The initial cost of this construction would be higher than the conventional mixes because of capital investment on AR plants. This is indisputable. However, in terms of higher life cycle cost due to longer life of the mixes, the cost differential might not be very big. Besides, with proliferation of technology, economies of scale and competition the cost would come down.

16.3 Quality Issues

It is feared that uniform quality of AR binder cannot be produced because of variability in properties of crumb rubber. Therefore, uniformity of quality over a project stretch and across many projects, cannot be ensured. This is a genuine apprehension. However, the variability in quality can be solved by quality assurance procedures and controlling design based on the type of input materials.

16.4 Suitability in all Climatic Regions

General belief is that the requirement of high viscosity and high softening point binder (which the AR is capable of delivering) is relevant only for hot climate and not for colder regions where stiffer binders become brittle and crack prone. This is only partially true. Stiff and resilient binders are required everywhere to resist cracking and rutting. The elasticity in the binder provided by the rubber would make it useful in all conditions. The evidence of this is in the interest shown by colder regions of the World like Europe and other states in USA apart from the four pioneering states.

17 Notwithstanding the limitations of domestic research and doubts and apprehensions expressed, its advantages far outweigh these limitations and underline the need to exploit the potential of this technology in providing rut and crack resistant, durable, high performing quieter pavements and helping the environment by recycling the wastes, which is already established in numerous countries. Data generated from field can further fine-tune the technology.

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