QUALITY CONTROL REQUIREMENTS FOR USING CRUMB RUBBER MODIFIED BITUMEN (CRMB) IN BITUMINOUS MIXTURES


By

Prof. Prithvi Singh Kandhal
Associate Director Emeritus
National Center for Asphalt Technology
Auburn University, Alabama USA

ABSTRACT

Crumb rubber modified bitumen (CRMB) was used in numerous asphalt paving projects in all 50 states of the Unites States from 1991 to 1995 due to a federal government mandate. Most states discontinued the routine use of CRMB after the mandate was repealed in 1995. There are three primary reasons for this.

First, the use of CRMB requires development of a statewide infrastructure consisting of strategically located blending terminals or on-site blending units. This is required because CRMB must be used as soon as possible since its quality can start to deteriorate as early as 6 hours after production. Crumb rubber is prone to degradation (devulcanization and depolymerization) if its use is delayed thereby losing its vital properties such as elasticity and viscosity.

Second, crumb rubber tends to separate and settle down in the bitumen. If some crumb rubber particles have settled to the bottom of the transport tanker or contractor’s storage tank, the CRMB at the top may have quality, which is inferior to pure bitumen. This happens because the crumb rubber at the bottom has robbed (absorbed) aromatic oils from the bitumen. In such cases, the CRMB actually used can be detrimental to the bituminous pavement. Therefore, after production CRMB should be agitated continuously through mechanical means during its transportation and its storage in contractor’s bitumen tank.

Third, many states in the US have reported mixed performance of asphalt pavements constructed with CRMB and the cost effectiveness of CRMB was found to be none to marginal.

At the present time, CRMB is used on a routine basis only in four states in the US. The remaining 46 states do not appear to have much interest in developing the necessary infrastructure and implementing the necessary quality control programme to ensure effective use of CRMB. The objective of this paper is to describe all necessary quality control requirements for using CRMB in bituminous mixtures so that both producers and
users alike can assess whether in a developing country like India there is the necessary infrastructure and quality control programme in place for the effective use of CRMB.

1. INTRODUCTION

Rubber from discarded tyres has been used in various highway applications for over 50 years. Generally, the tyre rubber is ground to a particulate or crumb prior to adding it to bitumen. This form of the tyre rubber is called Crumb Rubber Modifier (CRM)\textsuperscript{5,15,21}. When CRM is added to bitumen, the resulting product is called Crumb Rubber Modified Bitumen (CRMB). In the United States CRMB is simply called Asphalt-Rubber (AR).

Charles McDonald, who was an engineer with City of Phoenix, Arizona, US, developed the AR technology in the early 1960s. The use of AR or CRMB was sporadic in the US until 1991, when the US Congress mandated its use in all 50 states through central legislation. This was done in spite of the fact that the performance of asphalt pavements with CRMB was mixed in the US at that time\textsuperscript{23}. Whereas in some projects the CRMB enhanced the performance of the asphalt pavement, there was no significant improvement in other projects. This political decision by the US Congress, which was not based on sound engineering principles, was opposed both by the asphalt industry and the state highway departments’ officials at that time.

Since most of the states did not have any experience in using CRMB, the US Federal Highway Administration (FHWA) undertook an ambitious practical training programme for state highway engineers. The author of this paper was privileged to participate in preparing the CRMB Training Manual\textsuperscript{13} and also act as an instructor for the CRMB technology. The training emphasized the importance of stringent quality control requirements right from the production of the CRMB at or in close proximity of hot mix asphalt plant; transportation of CRMB from production site to asphalt mix plant; storage of CRMB in contractor’s plant; and final testing of CRMB just prior to adding it aggregates in asphalt plant pug mill or drum.

During the mandate all 50 states in the US used CRMB in numerous asphalt paving projects from 1991 until 1995 when the mandate was repealed\textsuperscript{8,12,14}. Thereafter, most states discontinued the routine use of CRMB in asphalt paving mixtures. There are three primary reasons for this.

First, the use of CRMB requires development of a statewide infrastructure consisting of strategically placed blending terminals or on-site blending units. This is required because CRMB must be used as soon as possible because its quality can start to deteriorate as early as 6 hours after production. This will be discussed in detail later.

Second, the quality control requirements right from the production to the end use of CRMB are too cumbersome because of two issues: (a) crumb rubber tends to separate and settle down in the bitumen and (b) crumb rubber is prone to degradation.
(devulcanization and depolymerization) if its use is delayed thereby losing its vital properties including viscosity\textsuperscript{10,17}. Some patented CRMB processes such as “chemically modified” CRMB, have been developed in the US and Canada recently to overcome the problems of separation and/or degradation\textsuperscript{4}. However, after adding patent royalties the cost of improved CRMBs approximates those of conventional polymer modified bitumens (PMB) such as those modified with SBS. In that case state highway agencies would prefer to use conventional PMBs which are closely controlled and do not have any problem with degradation or separation. That is why the use of “chemically modified” CRMB is not common in the US. Moreover, such “chemically modified” CRMBs undergo a rigorous laboratory and field evaluation by the state highway agencies to verify the claims of the suppliers concerning separation and degradation. Such evaluations are considered public information and are usually published.

Third, many states such as Arkansas, Georgia, Kansas, Minnesota, Nevada, Washington, and Wisconsin\textsuperscript{1,2,7,9,11,19,22,24} have reported mixed performance of asphalt pavements constructed with CRMB and the cost effectiveness of CRMB was found to be none to marginal\textsuperscript{6}.

At the present time, CRMB is used on a routine basis only in four states in the US: Arizona, California, Florida, and Texas. The remaining 46 states do not appear to have much interest in developing the necessary infrastructure and implementing the necessary quality control programme to ensure effective use of CRMB. The objective of this paper is to describe all quality control requirements for using CRMB in bituminous mixtures so that both producers and users alike can assess whether in a developing country like India there is the necessary infrastructure and quality control programme in place for effective use of CRMB. If not, the use of CRMB will be counterproductive. As explained later, in some cases the quality of CRMB can be inferior to that of the neat bitumen to which rubber was added.

2. PRODUCTION OF CRMB

CRMB is produced by the so-called wet process in which crumb rubber is added to hot bitumen and the mixture is agitated mechanically until there is a “reaction” between the bitumen and crumb rubber. The “reaction” is not a chemical process but rather a diffusion process that includes the physical absorption of aromatic oils from the bitumen into the polymer chain of the rubber. The rubber particles swell as they absorb oils, which cause the viscosity of the CRMB to increase during the first hour or so\textsuperscript{3}. After the “reaction” and associated swelling is over, the viscosity of the blend levels off as shown in Figure 1.
If the CRMB is maintained at high temperature for a prolonged period of time (as little as 6 hours), the crumb rubber begins to degrade (devulcanize and depolymerize) causing the CRMB viscosity to decrease from its plateau level (also called the target viscosity) as shown in Figure 1. This time versus viscosity plot of CRMB during production and storage is influenced by the following factors.

a. **Bitumen Crude Source and Method of Refining**

The chemical composition of bitumen varies from one petroleum crude source to another, from which it is refined. No two crude sources are the same. The method of refining also affects bitumen’s chemical composition in terms of asphaltene and maltene contents. Since bitumen is a hydrocarbon and crumb rubber also contains substantial amounts of hydrocarbons their mutual chemical compatibility affects the time versus viscosity curve mentioned earlier. The type and amount of oil readily available in bitumen for absorption by crumb rubber also affects the nature of the curve. Bitumens low in aromatic oils tend to produce CRMB with poor adhesive properties.

b. **Source of Crumb Rubber**

Crumb rubber can be obtained from truck tyres or automobile tyres or both. Truck tyres contain 80 percent more rubber hydrocarbons than automobile tyres and also contain significantly higher amounts of natural rubber. Whole truck tyre contains 18 percent natural rubber compared to 9 percent in an automobile tyre and 2 percent in tyre treads. The amount of natural rubber has shown to affect the properties of CRMB significantly. Each lot of crumb rubber may have different chemical composition depending on the source (truck tyres or automobile tyres or mixture of both) and, therefore, when combined with the same source of bitumen may give different time versus viscosity curve. In other words, the target (plateau) viscosity and the allowable time before degradation are unique to each specific combination of bitumen and crumb rubber. Any time the source of bitumen or crumb rubber is changed, the time versus viscosity must be obtained again.
c. Method of Producing Crumb Rubber

Crumb rubber is produced from discarded tyres by two methods: (a) grinding at ambient temperatures and (b) grinding cryogenically cooled tyre rubber. In the latter process, the tyre rubber is chilled by liquid nitrogen. The resulting brittle rubber is then easily fractured in a hammer mill and then ground. Grinding at ambient temperatures produces sponge-like crumb rubber particles with high surface area, which reduces the “reaction” time when mixed with bitumen. Cryogenically produced crumb rubber generally has smooth particle surface texture with low surface area and needs increased “reaction” time. The processing method, therefore, affects the crumb rubber particle morphology, which in turn affects the rate of reaction and target viscosity of CRMB.

d. Amount and Size of Crumb Rubber

The finer the size of the crumb rubber, the lesser is the time of “reaction” before the viscosity plateau is reached. For a given percentage of crumb rubber, the “reaction” time is directly proportional to the diameter squared of the rubber particles. Both the amount and size of crumb rubber affect the properties of CRMB.

The preceding four factors among others, which affect the time versus viscosity curve, are unique to each producer of CRMB. Therefore, every producer (refinery, blending terminal, or on-site blending) must obtain this curve for a time of at least 24 hours (X-axis) and furnish it to the user agency (asphalt mix contractor or government highway department). This can be accomplished by measuring the viscosity of the CRMB every 10-15 minutes during the “reaction” before reaching the viscosity plateau and every one-hour up to 24 hours after the “reaction” has taken place. Rotational viscometers such as Brookfield (Figure 2) and Haake are used for measuring the viscosity. This will also allow the producer to furnish the following to the user agency: (a) target (plateau) viscosity and (b) allowable time in hours before the CRMB starts to deteriorate (reduction in viscosity as shown in Figure 1). The user agency then ensures that the CRMB is used within allowable time after production. The user agency also checks the viscosity of CRMB just prior to adding it to hot aggregate and compares the measured viscosity with the target viscosity furnished by the CRMB producer. A portable handheld viscometer such as Haake viscometer (Figure 3) can be used in the field. The allowable time includes storage at the CRMB production site, if any; transportation time from the production site to contractor’s asphalt plant; and storage in contractor’s tank.

3. TRANSPORTATION OF CRMB

Even after the crumb rubber has “reacted” with bitumen, it has a tendency to separate from bitumen partially and settle down during transportation and storage at the contractor’s plant until CRMB is used. Therefore, it is essential that the truck tankers carrying CRMB are equipped with heavy-duty recirculation devices or mechanical
agitators to keep the crumb rubber in suspension. The CRMB supplier should measure and verify the viscosity of CRMB at the time of delivery to the user agency.
If there is a phase separation or degradation of crumb rubber during transport it will be indicated by the measured viscosity when compared to the target viscosity. That is why, the few states in the US, which use CRMB on a routine basis at the present time require that the CRMB should be used within a specified number of hours after production. For example, California, Kansas, and Arizona specify that the CRMB must be used within 4, 6, and 10 hours, respectively. This kind of requirement does not allow the CRMB to be produced at oil refineries, which are generally far away from asphalt mix plants. That is why, an infrastructure of numerous blending terminals or on-site blending units are necessary within a state. Figure 4 shows such infrastructure strategically located in the State of Florida in the US.

![Figure 4. CRMB Blending Infrastructure in the State of Florida](image)

### 4. USE OF CRMB AT ASPHALT MIX PLANT

Attempt should be made to use the CRMB as soon as it is delivered to produce the asphalt mix. The contractor’s bitumen tank should be equipped with heavy-duty recirculation pumps or mechanical agitators to keep the crumb rubber particles from settling. If some crumb rubber particles have settled to the bottom, the CRMB at the top may have quality, which is inferior to pure bitumen. This happens because the crumb rubber at the bottom has robbed (absorbed) aromatic oils from the bitumen. In that case, the CRMB actually used can be detrimental to the bituminous pavement. Prolonged storage of CRMB in the contractor’s tank can also cause degradation of the CRMB as mentioned earlier. If there are potential delays in using the CRMB such as those from equipment breakdown or weather, the CRMB should be allowed to cool down. It should be reheated slowly (avoid spot heating) and mixed prior to use.
contractor must also check the viscosity of the CRMB just prior to adding it to pug mill or drum of the asphalt plant. The measured viscosity should compare reasonably well with the target viscosity supplied by the CRMB producer. If the measured viscosity is significantly lower than the target viscosity, separation of crumb rubber and/or degradation of crumb rubber are suspected and the CRMB should not be accepted for future use.

5. CONSTRUCTION QUALITY CONTROL

Construction of bituminous pavement with CRMB\textsuperscript{10} is not much different than construction with conventional bitumen except the following:

(a) Soapy water or silicone emulsion should be sprayed on truck beds so that asphalt mix does not stick to the bed. Use of diesel is not desirable at all for this purpose.

(b) Since the viscosity of CRMB is more than that of unmodified bitumen, higher mix temperatures are needed to obtain adequate compaction of the pavement.

(c) CRMB sets faster than unmodified bitumen. Therefore, compaction of asphalt mix should begin promptly after lay down by the paver. If the mix has cooled down, it may not be possible to obtain adequate compaction, which is very important for pavement durability.

(d) Pneumatic-tyred rollers tend to pick up the asphalt mix containing CRMB and, therefore, should not be used.

6. SUMMARY OF QUALITY CONTROL REQUIREMENTS

CRMB must be used in the asphalt mix as soon as possible after it is produced because its quality can start to deteriorate from degradation of rubber as early as 6 hours after production. The crumb rubber in the CRMB has a tendency to settle down and, therefore, CRMB must be mechanically agitated continuously during transportation and storage until it is used. The viscosity of CRMB should be monitored right from production to the end use in asphalt mix to detect degradation of crumb rubber and/or partial settlement of crumb rubber. The preceding general requirements necessitate development of an infrastructure within each state consisting of on-site blending units at asphalt mix plants and/or strategically located blending terminals which can deliver CRMB as early as 6 hours to the asphalt mix plant in a geographical region (see example in Figure 4). All blending facilities must have testing equipment (especially rotational viscometers) for quality control and quality assurance of CRMB.

The following is a brief summary of quality control requirements when CRMB is used in bituminous mixtures.

- CRMB producer must develop and document time versus viscosity curve for each specific combination of bitumen and crumb rubber\textsuperscript{10}. Whenever the source of bitumen and/or crumb rubber changes, a new curve should be obtained. This curve establishes the CRMB target viscosity and the time in hours available after
production before the crumb rubber starts to degrade. This curve along with the
target viscosity and available time after production should be furnished to the user
agency (asphalt mix contractor or government highway department) to which
CRMB is being supplied. The amount of crumb rubber in the CRMB must also be
furnished to the user agency.\(^{10}\)

- The crumb rubber in CRMB has a tendency to separate from bitumen and settle
down. Therefore, after production CRMB should be agitated continuously
through mechanical means during its transportation to asphalt mix plant and its
storage in contractor’s bitumen tank.
- Since CRMB is substantially stiffer than unmodified bitumen, compaction of
asphalt mix containing CRMB should begin promptly to adequate compaction in
the pavement.

7. RECOMMENDATIONS

The use of CRMB has been encouraged in India with good intention to increase the
service life of bituminous pavements. This was based on good results obtained on test
roads evaluated by the Central Road Research Institute and some universities\(^{18}\).
However, test roads are constructed under closely controlled conditions resulting in
good quality. As was found in the US, when the technology is implemented full scale
in the field the ground realities (in terms of necessary infrastructure and quality
control programme) are different from those experienced in test roads. If CRMB is to
be used in a cost effective way and with success, necessary infrastructure for blending
CRMB at or in close vicinity of all asphalt mix plants (see example in Figure 4) and
associated quality control programme as mentioned in the previous summary, need to
be established. In absence of an adequate infrastructure and quality control
programme, which is generally the case in a developing country like India, the use of
CRMB is not justified and may even be detrimental at times to the quality of
bituminous road pavements.

CRMB should not be promoted for the sake of disposing discarded tyres because
there are many other uses. Whole or shredded tyres have been used in the US for
combustion to produce electricity and as fuel in lieu of coal in brick and lime kilns.
Pound by pound tyre has more BTU than coal. Tyres have also been used in highway
related applications including fills, embankments, erosion control devices, slope
protection, and safety hardware. Tyres are being shredded and pieces are being used
already as a fuel in lieu of coal in brick kilns in India.

CRMB should also not be promoted to increase the stiffness of the 60/70 penetration
bitumen because substituting viscosity-graded AC-30 bitumen for 60/70 bitumen,
which is long overdue, will serve the same purpose without any increase in cost.
8. REFERENCES


The following is the author’s response to Shri R. C. Jindal’s comments:

The author is well acquainted with the IRC and BIS guidelines for use of polymer and rubber modified bitumen. The CRMB developed in India since 1999 is not significantly different than the CRMB developed in the US earlier. In both cases, CRMB is produced by the so-called wet process, in which crumb rubber is added to hot bitumen and the mixture is agitated mechanically until there is a “reaction” between bitumen and crumb rubber. The law of physics – settlement of crumb rubber, which is in suspension, by gravity – applies to both. The law of chemistry – vulcanized crumb rubber has a potential to degrade when kept in hot bitumen for a prolonged period of time – also applies to both. Shri Jindal has made a simple statement that CRMB developed in India is different than that developed in the US without citing specific differences in the process involved.

The primary objective of the paper was to describe certain quality control requirements, which are needed in view of the aforementioned two laws of nature. For example, continuous agitation of CRMB to avoid settlement of crumb rubber particles, and use of CRMB as soon as possible before degradation of crumb rubber takes place, are needed. Unfortunately, the existing IRC and BIS guidelines do not address adequately the quality control requirements for CRMB.

The decision to produce CRMB only at the refineries was probably taken in earnest in India because of the potential difficulty in ensuring quality control at or near hot mix plants. However, we are now faced with the following two potential problems:

1. Settlement of crumb rubber during transportation (we do not have tanker trucks in India which have re-circulation capability while trucks are moving) and during storage in contractor’s tank (which usually do not have re-circulation or agitation capability).
2. Degradation of crumb rubber in as little as six hours.

Therefore, we have a dilemma; we are between a rock and hard place.

Shri Jindal has stated “the claim of author that rubber starts separating is totally false and cannot be implied on CRMB being produced by IOC in India at refineries.” Unfortunately, the problem of the crumb rubber settling at the bottom of the tanker, coming from refineries, is indeed a real one and has been documented in 2004 by government engineers engaged in national highway construction in Rajasthan and Uttar Pradesh, as is evident from the following quotations which are on record:
“It is understood that whenever a truck tanker carrying refinery made CRMB bitumen is emptied at the Hot Mix Plant of the contractor, a layer of 3 to 4 inches thickness of molten rubber material is found at the bottom of the tanker. This molten deposited rubber material is removed by the tanker transporter with extra efforts and difficulty and thrown away somewhere before going for the next trip to the refinery. It appears that about 25 to 30% of rubber content in the CRMB mass being transported is going waste converting the remaining available CRMB material into altogether a different substance. This segregation of rubber content of CRMB is occurring perhaps due to inefficient, improper and inadequate blending process. This defeats seriously the very purpose of using modified bitumen in the highway profession.”

“Reheating of CRMB: The CRMB is transported in bulk and stored in bitumen tank. While heating, the whole of bitumen in the storage tank gets heated. The unused bitumen after a days work has to be reheated before use. This reheating results in loss of elasticity. Segregation of rubber and bitumen has also been reported after its storage for 3-4 days.”

Whenever, these two potential problems: settlement and degradation of crumb rubber are mentioned, it is argued that the CRMB in India is “chemically treated” and therefore, these problems do not exist at all. The author has attempted to search CRMB related technical literature in India and has also discussed this matter with some CRMB suppliers and user agencies. However, the author could not get satisfactory, direct answers to the following logical questions:

1. What exactly do we mean by “chemically treated” CRMB in India? Does any agency have a patent on this, like it is done in the US? If so, what is the patent number and who holds it? If there is no patent, which are the approved chemicals (gilsonite, resins, etc.) and/or associated processes? Who approved them?
2. Where is the published or reported systematic material research data in India, which confirmed that the so-called “chemically treated” CRMB does not present settlement and degradation problems?
3. Was “chemically treated” CRMB used in the test roads evaluated by the CRRI and other institutions? Is the “chemically treated” CRMB being supplied now is identical to that used in those test roads? If yes, how do we know unless the material was properly characterized, compared, and data published? If no, how do we know that the new material will have similar performance in the field?
4. According to Shri Jindal, IOC is conducting viscosity tests for CRMB produced by it before delivery to the customer and CRMB is also tested at site. The author has not seen any published CRMB quality control data (from the supplier) nor quality assurance or verification data (from the user agencies). Instead of simply claiming it is done, it is high time such data is published if indeed it is available.

Lastly, Shri Jindal has stated, “Some private agencies are also producing CRMB and it is essential to check whether they are using chemically treated crumb rubber mixed with hydrocarbon material or not. In case any firm is producing CRMB with plain crumb rubber then the observations of the Paper No. 522 shall apply to that product.” The
author’s question is: how do we check? We need the answers to author’s question No. 1 above to do that. Unfortunately, to author’s knowledge we do not have those answers yet. This should of serious concern to the specifying and user agencies.

Shri Mamdapure has asked whether there are any tests for crumb rubber to be mixed with bitumen. Yes, there are physical and chemical test requirements to ensure the quality of crumb rubber reclaimed from old tyres. Unfortunately, we do not have such requirements in India. In the US, the user agencies have physical requirements for the crumb rubber such as gradation, specific gravity, moisture, and metal contaminants and chemical requirements such as Acetone content, hydrocarbon content, ash content, carbon black content, and natural rubber content. All these requirements are given in Reference 10 of the paper.

Shri Mamdapure has also asked whether CRMB can be reheated. Yes, it can be reheated but it should be done gradually and uniformly. Only indirect heat through oil filled tubes rather than direct heat (or flame) should be used to avoid damaging bitumen and rubber.

Shri Sagane has asked what type of stirring and temperature maintenance arrangements should be specified for tanker/storage of CRMB in tender documents. Any suitable mechanical agitation device or heavy-duty re-circulation pumps can be used to keep the crumb rubber in suspension during transportation and storage in contractor’s tank. Only indirect, uniform heat should be used to maintain the desired temperature. The time-viscosity chart is required only during the production of CRMB by the manufacturer. The user (contractor or Government agency) should test the viscosity of CRMB at the time of delivery for comparison to production target viscosity as explained in the paper.

Shri Sagane is right that we are leaving many aspects of quality control on manufacturers and thus are dependent upon them. It is high time the users take control and start checking the quality of CRMB at the point of delivery rather than relying on verbal assurances from the suppliers.

Shri Puri has asked whether the author has carried out any test on the CRMB available from refineries like IOC. The author is a retired asphalt engineer who does not have any vested interest and who is not affiliated with any private or government agency in India. It is not his responsibility to conduct any test on CRMB produced in India at his expense; rather it is the responsibility of the suppliers to conduct extensive quality control (QC) tests and the responsibility of the user agencies (contractors and government) to conduct the quality assurance (QA) tests on samples obtained at the place of delivery. Rather than simply claiming that QC/QA tests are conducted, such test data should be analyzed statistically and published for the information of the highway community at large, if indeed such data is available.

Shri Rampal has asked whether polymer modified bitumen (PMB) is also prone to degradation or separation. There are some PMBs (which use certain plastomers or use elastomers which are incompatible with bitumen), which may be prone to phase separation. Therefore, it will be prudent to use re-circulation or mechanical agitators to ensure a homogeneous product.
Shri Kumar has asked under what conditions CRMB should be preferred over 60/70 or 30/40 grade especially when so many quality controls are required for CRMB thereby increasing its cost. Modified bitumens are used in the US under two primary conditions: (a) when neat bitumen is not suitable for extreme climate (the difference between highest and lowest pavement temperatures exceeding 90°C) and (b) high volumes of heavy traffic. Since we do not have extreme pavement temperatures in most of India, modified bitumens should be used in India on roads with high volumes of heavy traffic only. Unfortunately, we are also using CRMB on low-volume rural roads (such as Pradhan Mantri Grameen Sarak Yojna) resulting in higher expenditures, which are not justified at all technically. In fact softer bitumens such as 80/100 will be more durable than 60/70 on low-volume roads. CRMB is even stiffer than 60/70 so it is not desirable.

Shri Kumar has further asked what are MORTH, IRC and CRRI’s initiation to standardize the production and using of CRMB in a big way. Probably it was done to improve the durability of roads in India. However, it cannot be achieved unless an effective QC/QA programme is implemented.

Shri Kumar has mentioned that he has implemented the use of CRMB in wearing course in NHAI projects in A.P. and it is performing very well. Has he constructed a control test section (using neat 60/70 bitumen only) in every project (which he and others should) for comparing the performance of CRMB section with a neat bitumen section. If not, we cannot state simply that CRMB is performing better. It is high time more and more government agencies also build control test section in every CRMB project so that we can accumulate a vast amount of historical performance data in every state and under different conditions. This is a common practice in the US.

Shri Ganesu has enquired about the optimum time limit to use the CRMB after production and transportation as per time-viscosity curve. As mentioned in the paper, the minimum time when CRMB can start to degrade can be as little as six hours. The maximum time is dependent on several factors (such as chemical compositions of rubber and bitumen and their compatibility; rubber size and gradation; mode of crumb rubber manufacture (ambient or cryogenic grinding), and blending and storage temperature) as mentioned in the paper.

Shri R. S. Sharma has stated that some manufacturers of CRMB in India contend that their process of manufacturing CRMB is different and therefore there is no effect of the time/duration of use after manufacture. Shri Sharma has asked the author to throw some light on how to ensure that a particular supply has treated or untreated CRMB rubber. That exactly is the question, which the author would like to ask the manufacturers who claim that their CRMB is “chemically treated” and the user agencies (contractor and government) that are accepting the so-called “chemically treated” CRMB. As mentioned in author’s response to Shri Jindal earlier, we continue to use the so-called “chemically treated” CRMB without exactly knowing what it is or having the ability to verify it. The author has not seen any published QC/QA data to indicate that the so-called “chemically
CRMB alleviates separation and degradation problems during actual transportation in tanker trucks for a number of days.

Shri R. S. Sharma has also asked to clarify the effect on the properties of CRMB with repeated heating. Repeated heating of CRMB is very likely to cause degradation of crumb rubber in bitumen and therefore should be avoided.

Shri Joseph has asked whether the same kind of stringent quality control is required in the case of Natural Rubber Modified Bitumen (NRMB). The author is not very knowledgeable about NRMB but does know that the NRMB is more sensitive or prone to degradation as compared to CRMB when kept at high temperatures for prolonged period of time. That is why, IRC SP 53 has a caution, “In case of NRMB, material shall be supplied at 130-150 C and shall be used within 24 hours of its filling.”

Shri Joseph mentions that, “unfortunately it has become the practice of developed countries to dump their obsolete technologies in developing countries”. The author disagrees with this statement. As mentioned in the paper, only four states in the US use CRMB routinely. The remaining states do not want the hassle of stringent quality controls associated with the use of CRMB, they would rather use SBS modified bitumens. Some manufacturers in India claim they have developed the technology of “chemically treated” CRMB in India itself. Therefore, no country has dumped this technology on India. Rather we have adopted it voluntarily without paying attention to the associated quality control requirements, which are available in extensive literature on CRMB.

Shri B. P. Jain has asked how can we effectively use readymade CRMB in remote areas supplied by various companies in India with reference to viscosity requirements. The only solution is to use portable blending units for making CRMB at or in the vicinity of asphalt mix plant. There should be a specification for the quantity and quality of crumb rubber. A well-equipped testing laboratory manned by a qualified technician should support the blending unit.

Shri R. K. Singh has asked whether we are using the CRMB produced in refinery, which has lost its viscosity due to long time taken in transportation. The answer is probably yes, because the author has not seen any published paired viscosity data from the refineries at the time of loading and at the time of delivery. Shri Singh then asks, “Which is superior, CRMB or polymer modified bitumen?” Most state highway departments in the US use polymer-modified bitumens (PMB), which must meet the Superpave Performance Graded (PG) bitumen specifications. It is believed that the performance of well-designed PMBs is superior and more predictable than that of CRMB, which depends on the compatibility of crumb rubber with bitumen (both are very complex hydrocarbons). In the US it is the owner’s choice whether to use CRMB or PMB. The same choice should also be given to the state highway agencies in India.

Dr. Raju has mentioned that quality control is a must whether it is a straight bitumen or CRMB or PMB. He says when chemically treated, finely divided crumb rubber can solve
the problem, why not try it? Unfortunately, CRMB requires much more quality control compared to neat bitumen and PMB. We also do not know what the “chemical treatment” in CRMB is, so we cannot check it. We are already using it based on the “assurance” from the manufacturers and some organizations that it is really a good material, which is superior to what is used in the US. Frankly, we have no way of knowing it at the present time.

Shri Mahalahe has asked questions about the shelf life of CRMB and mobile blending units. These questions have already been answered in response to other comments.

Dr. Parida has asked at what temperature and rate of shear the viscosity test is conducted for CRMB. ASTM D6114-97 Standard Specification for Asphalt-Rubber (CRMB) requires a rotational (Brookfield) viscometer to be used to determine apparent viscosity of CRMB at 175 °C. The viscosity test method should conform to ASTM D2196 Method A, which uses Spindle 3 at 12 rpm or 20 rpm depending on the model of the Brookfield viscometer. If a portable Haake viscometer is used it must be calibrated with Brookfield measurements.

Shri A. K. Sharma has asked how to obtain proper rubber content and bitumen content in an asphalt mix made with CRMB. Unfortunately, it is not easy to determine accurate rubber content and bitumen content in such mixes when conventional asphalt extraction methods are used. This is due to the fact that extremely fine crumb rubber particles pass through the extraction filter along with bitumen and therefore become part of the bitumen content. The larger size particles of crumb rubber end up with the extracted aggregate and can be separated from the aggregate as follows. Prepare a saline water solution (1 part salt and 3 parts distilled water) and immerse the extracted aggregate containing rubber particles in it. Agitate the mix and allow the sample to stand for at least 30 minutes. The rubber particles should float whereas mineral aggregate particles will settle. Skim off the floating rubber particles, dry them and weigh. For an accurate determination of total CRMB content it is recommended to use ASTM D 6307, “Asphalt Content of Hot Mix Asphalt by Ignition Method”, which was developed at the US National Center for Asphalt Technology.

Shri Mahajan has asked whether any studies have been made for Plastic Waste Modified Bitumen. Extensive studies have been made on the use of polyethylene in bitumen, which are generally applicable to the use of plastic waste as well. Again, since plastic cannot be dissolved in bitumen and remains in suspension, the blend has to be agitated continuously until it is used. Therefore, portable blending units are used in the US to supply polyethylene-modified bitumen to hot mix plant. A proper infrastructure is also required for collecting, sorting and processing of the plastic waste to remove contaminants. If we are planning to use plastic waste in bitumen in future we must prepare well-thought out specifications, test methods, guidelines, and QC/QA programme.

Shri Mishra has raised a valid concern about the quality of automobile tyres, which may have aged excessively in storage. That is why; in the US most highway agencies have a specification requirement for the chemical composition of crumb rubber produced from
automobile tyres. The chemical composition specification gives a range for Acetone content, hydrocarbon content, ash content, carbon black content, and natural rubber content. These specifications are given in Reference 10 of the paper. Unfortunately, we do not have any specification in India for the quality nor the minimum quantity of crumb rubber in CRMB. We are totally relying on the CRMB manufacturers.

Shri A. K. Singh has recommended developing instruments for testing CRMB prior to its use in road construction so that we can avoid bad performance later. We do not have to reinvent the wheel. Such instruments are already developed and standard test methods are available as mentioned in the paper. Test methods are available for measuring the viscosity, elastic recovery, and resilience of CRMB. What is required is a strong will and determination for their implementation in India through adequate specifications, guidelines, and quality control in the field at the time of delivery.

Dr. P. K. Jain of CRRI has made several general statements without giving any specifics and references. He has stated that the “information pertains to only products of USA and misleading as some failures pertained to structural and quality control problems.” He has not cited any study or references to support this statement. All information in the author’s paper is supported by numerous references cited at the end of the paper. Then, Dr. Jain adds, “degradation of CRMB pertains to older case histories but recent technology has been improved as reported by author himself.” Yes, there are 3-4 patents in Canada and US for chemically treated CRMB. However, the use of these patented products in the hot mix asphalt is almost negligible in the US and therefore there is no performance history. The four states, which routinely use CRMB (some are forced to use because of state law) use conventional CRMB without any chemical treatment. As mentioned in author’s response to Shri Jindal earlier, we in India do not know what chemical processes are used by different refineries and private suppliers. How do we check the product? Where is the QC/QA data? Dr. Jain should try to answer these specific questions so as to ensure transparency.

Dr. P. K. Jain has further stated that technologically there is great difference in CRMB produced in India and USA: CRMB in USA contains 20% rubber while in India it is restricted to 8-10%; coarser rubber is used the US while finer rubber is used in India; and Indian tyres contain higher natural rubber than US tyres which gives better performance. All of the above three statements are not correct based on data given in Reference 10 of the author’s paper. In the US, the rubber content in CRMB varies from 8 to 20% depending on state highway agency specifications, and minimum rubber content is also specified. We simply do not know how much rubber we are getting in India because we do not specify the minimum rubber content at all. Whereas Dr. Jain says it is restricted to 8-10% in India, where is the specification? Contrary to Dr. Jain’s assertion, both coarse and fine rubber gradations are used in the US depending on the state specification (see Reference 10 of the paper). Concerning the amount of natural rubber in tyres, the percentage of natural rubber is generally higher in truck tyres and relatively lower in car tyres. These percentages do not vary significantly from country to country because the tyre technology is essentially the same throughout the world.
Concerning the time-viscosity tests conducted by CRRI at 150°C, please see author’s detailed response later to Dr. M. C. Jain of IOC who conducted similar experiments. First of all, this temperature is too low to conduct such tests because it is significantly lower than 165 to 185°C temperature range specified for CRMB binder in Table 8 of IRC:SP:53-2002. Secondly, Dr. P. K. Jain has not cited any reference where the CRRI data is published.

Dr. P. K. Jain has given four reasons as to why CRMB in India has a lower tendency of separation: only 8% rubber; higher natural rubber content; better technology; and better quality assurance at refineries. As mentioned earlier, there are no specifications in India on rubber contents so there is no way of verifying it. Unless Dr. Jain gives specifics the author cannot understand what is meant by “better” technology. Also, we have not seen any published quality assurance data on CRMB at the point of delivery.

Dr. P. K. Jain has mentioned about a time-temperature relationship study conducted by CRRI, which in his opinion is contradictory to the observations of the author. The fact is that the author has mentioned time-viscosity relationship in the paper and not time-temperature relationship. Any way, where is the CRRI study on time-temperature relationship published?

Dr. P. K. Jain lastly mentions about improved performance of NH 8 where CRMB was used. The author does not question this observation. However, we would like to know the characteristics of the “chemically treated” CRMB used on that project. Are all suppliers still supplying us with similar CRMB? If so, how do we know it?

Shri Dibyajyoti Sharma has suggested supplying CRMB in drums, which are cooled right after filling so that time dependent settlement and degradation problems do not occur. His suggestion is technically correct. However, we have to be careful when we reheat the CRMB in drums prior to use. We must apply indirect heat only and that too gradually to raise the temperature of the CRMB to the desired mixing temperature. Rapid and direct spot or flame heating is detrimental to CRMB. After heating, the CRMB should be tested for specification compliance.

Besides Ring & Ball softening point test for CRMB suggested by Shri Sharma, it is very important to conduct the elastic recovery test at the time of delivery because only the latter test will indicate whether the CRMB contains proper amount of crumb rubber or not. The manufacturer can obtain high softening point by using hard bitumen or adding Gilsonite (which is rock bitumen with 0 penetration) without adding any rubber.

The author has mentioned testing viscosity of CRMB every 15 minutes during CRMB production only in refinery or portable blending units so as to confirm that crumb rubber has “reacted” (or swelled) completely with bitumen. It is not required in the field.

The author agrees with Shri Sharma that we must conduct more research on chemical treatment of CRMB for increasing the time period between production and actual use.
However, such research should be transparent and should be publicized among the highway community.

It has been commented by Dr. M. C. Jain of IOC that CRMB samples are regularly monitored and checked by IOC R&D for their quality. Actually, there is a need to test CRMB samples at the time of delivery to the hot mix contractor after transportation in tankers (which are mostly not capable of re-circulating or agitating the CRMB while moving) for over 24 hours. Only then, we will ascertain whether the crumb rubber has separated and/or degraded. In other words, IOC should report paired CRMB test data on production versus delivery samples to support their argument that the CRMB maintains its integrity after transporting over long distances. IOC’s attention is also drawn to the separation problem documented by field engineers as quoted earlier in response to Shri Jindal’s comments.

Dr. M. C. Jain has reported results from a “recent” study conducted by storing CRMB-60 for a period of seven days and has concluded that the quality of CRMB does not change appreciably. The author is not surprised at this conclusion because the CRMB was stored in this study between 130 to 150 C temperatures only, which is significantly lower than 165 to 185 C temperature range specified for CRMB binder in Table 8 of IRC:SP:53-2002. ASTM D6114 specification for asphalt-rubber (CRMB) and some highway agencies in the US measure viscosity at 175 C temperature. Therefore, the temperature range of 130-150 C used by IOC is unrealistically low and therefore it is not surprising that it did not cause any significant degradation. IOC needs to repeat this study in the temperature range of 165 to 185 C and publish the test results.

The author concurs with the comments made by Shri Prabhash Singh. Contrary to what some people may want to believe, the problem of separation/degradation is a real one and must be confronted now and sorted out. This is confirmed by Shri Singh’s assertion that some regional officers of MORT&H have reported the separation problem and their letters are on record in the Ministry. The author also concurs with Shri Singh’s statement that either CRMB should be produced under controlled conditions in approved portable, on-site blending units (as is done in the four states of US: Florida, Arizona, California and Texas) or the use of SBS polymer modified bitumen (which is most prevalent in the US and is preferred by many state highway agencies) should be encouraged. The user agency must be given a choice whether to use CRMB or PMB, because it will be naïve to think that both have equal performance.

Shri Bhadraiah has stated that Department Officers in Andhra Pradesh have expressed their satisfaction about the quality of the CRMB supplied by the refineries. These are just “general” statements. Shri Bhadraiah should first determine whether these Department Officers have really sampled the CRMB at the point of delivery and tested it (for example, elastic recovery and softening point). If so, such data should be published to demonstrate that the so-called “chemically treated” CRMB is really effective. As engineers we need facts and figures and not general statements.
In closing, the author would like to make the following comments and recommendations in view of the preceding discussion.

- An independent, unbiased agency such as an IIT should be tasked to evaluate the quality of the so-called “chemically treated” CRMB supplied at the job sites by various refineries and private suppliers. Random CRMB samples should be obtained without any advance notice and tested for compliance with specification. That agency should also investigate and recommend test methods for the user agency to verify whether the supplied CRMB is indeed effectively chemically treated. The final report from that agency should be published as a public record. The user agencies should initiate and lead such efforts. We need engineering facts and figures rather than vague general statements that the CRMB produced in India is superior to that produced in the US.

- Compile and publish the CRMB quality control data (obtained by the suppliers) and quality assurance data (obtained by the user agencies) both at the time of loading the tanker and at the time of delivery to the hot mix contractor.

- All states should be required to construct a control section (at least one kilometer long) using neat 60/70 bitumen in every large project using CRMB. This would allow us to develop a vast performance database on neat bitumen versus CRMB in all states under different environmental and traffic conditions.

- CRMB should not be used on low-volume roads because it is too stiff a binder and will reduce the durability of such roads.

- Give the right of choice between CRMB and PMB to the state highway agencies. Do not impose on them to choose a binder based solely on cost considerations because that will always result in use of CRMB.

- Revise IRC SP 53:2002 to include the following as a minimum
  
  (a) Minimum rubber content in CRMB
  (b) Specification for crumb rubber based on physical and chemical properties
  (c) Emphasize mechanical agitation or re-circulation when tanker truck is moving and when CRMB is stored in contractor’s tank.
  (d) CRMB should invariably be sampled from each tanker load and tested for elastic recovery by the state highway agency, which should be given the necessary testing tools. If the rubber has settled, the load should be rejected.
  (e) Allow portable on-site blending units with stringent requirements on the blending equipment, testing laboratory, and trained technician. Crumb rubber quality should also be checked as per specification and minimum rubber content being added should be monitored.

Prof. Prithvi Singh Kandhal
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