

Performance Evaluation of Cold Mix with Use of Modifiers

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Abstract: Hot Mix Asphalt (HMA) is used predominantly as a paving mix from many decades in road construction. In India almost 90 percent road network is occupied by bituminous pavements only. Certain limitations associated with HMA use are like emission of green house gases from hot mix plant, shut down of plants during rainy season, problems in maintaining the paving temperature when hauling distances are more etc. Cold mix asphalt consists of unheated aggregate with emulsion or cutback as binder. Cold mix also offers advantages like; reduction in emissions, low fuel consumption, can be used in rainy seasons etc. The main difference between cold mix and HMA is that aggregates and emulsion or cutbacks are mixed at ambient temperature (10°C-30°C) in case of cold mix and aggregates and binder are mixed at high temperature (138°C-160°C) in case of HMA. In the emulsion based cold mix technology, the addition of pre-wetting water to the aggregate, thereafter addition of emulsion to it, production of the mix, laying and compaction, all processes are done at the room temperature (23°C to 25°C). In addition to this, field trials have proved that cold mix can be easily produced by using hot mix plant and laid in using similar techniques. They also found the performance of cold mixes in an acceptable level as cracks formed in cold mix bitumen pavement repaired themselves over time & because of this flexibility of cold mix surface it could last longer on low volume roads than hot mix. Cold mix can be used mainly for base course and sometimes for binder or wearing course. Bitumen is used largely for the construction of flexible pavements with Cold Mix technology. However, pavements may undergo one or several of the most common distresses i.e. rutting (permanent deformation under heavy vehicles loading) and fatigue cracking (cracks due to repetitive application of loads) at high in-service temperatures, and thermal cracking (cracks due to the lack of flexibility) at low in-service temperatures. To overcome these distresses, the performance of standard cold-mix bitumen may be improved by using modified bituminous emulsions, that is, by modifying bitumen properties before emulsification. Thus, cold-mix bitumen has been traditionally modified by addition of a large list of different types of substances called as 'modifiers'. Bitumen modification for paving applications is mostly carried out by means of polymers, both virgin (polyethylene, EVA, SBS, SBR, etc.) and waste (plastics from agriculture, crumb tyre rubber, etc.)

Keywords: Bitumen Emulsion, modifiers, cold mix, PVC powder

1. Introduction

Bitumen as a visco-elastic material plays a prominent role in determining many aspects of road performance. Various types of crude source and refining process lead to extreme complexity in bitumen chemistry and rheology. Furthermore, the rheological behavior of bitumen is also very complex, varying from purely viscous to elastic depending on loading time and temperature. A bituminous mixture needs to be flexible enough at low service temperatures to prevent pavement cracking and to be stiff enough at high service temperature to prevent rutting. Flexible pavements containing conventional bitumen do not always perform as expected.

In improving the properties of bitumen, several types of modification have been investigated. These include additive modification, polymer modification and chemical reaction modification. Bitumen modified with polymer offers a combination of performance related benefits as they improve the physical properties of the bitumen without changing the chemical nature of it. The polymer usually influences the bitumen by creating an inter-connecting matrix of the polymer through the bitumen. These additives increase the elasticity, decrease the brittle point and increase the softening point of the bitumen. This, in turn, will alter the properties of the mix in which such modified bitumen is used and these mixes will exhibit greater stiffness at higher temperature and high flexibility at low temperatures.

Various polymer modifiers based on nature (elastomer, plastomer and reclaimed type of crumb) are used for making perpetual pavements. The main aim of bitumen modification through polymers is to combine high cohesive strength at elevated temperature with elasticity at low temperature. Increase in the cost of polymer modified bituminous is offset by the enhanced useful life span of road surfacing. The capability of polymer modifiers is to resist the degradation of bitumen at mixing temperature.

2. Objective of Study

1. To carry out field and laboratory tests for the performance of polymer as modifier with their various percentages in cold bitumen mix.
2. To evaluate improved properties of cold mix by addition of polymer and rubber as modifier.
3. To compare the properties of cold mix with modifier and without modifiers.
4. To fulfill the requirement of the study, a laboratory tests has been carried out for semi dense cold mix with cement as additive and PVC powder as modifier.

3. Literature Study

3.1 Study of bitumen emulsion modification:

Shaffi et. al. (2011), specified that the history of asphalt emulsions and its application in road construction begin in the early part of 20th century. Today, up to 10% of paving-grade

asphalt is used in emulsified form compare to unmodified asphalt emulsion or hot applied polymer modified asphalt, polymer modified asphalt emulsion have several advantages. Emulsifying of polymer modified asphalt leads to a dried binder film that is more homogeneous and has a better polymer distribution which can improve the binder properties, particularly the ability of the binder to develop consistent cohesion strength and to have a better stone retention.

Forbes et. al. (2001) found that emulsifying of polymer modified asphalt show a good compatibility of polymer network distribution within asphalt compare to polymer modified asphalt. Polymer modified asphalt show incompatibility as the polymer has coalesced into localized agglomerations. The compatibility of the polymer within asphalt is important for optimum performance.

Overall, the use of polymer modified technology has been proven that it can improve the physical properties, performance, and durability of asphalt emulsion. For example, the used of polymer can improve the temperature susceptibility and rutting performance of cold mix. Certain polymer can be added at higher dosage level in asphalt emulsion compared to hot modified asphalt which means the improvement of polymer modified asphalt emulsion is better than hot polymer modified asphalt. The method to add polymer is depends on the physical properties of the polymer. Normally, the pre-blended method will be used for solid polymer and post-blended method will be used for liquid polymer. Even though the pre-blended method is proven to produce a fine polymer network within asphalt emulsion, some researchers suggested that post blended method should be used for liquid polymer to produce polymer modified asphalt emulsion to reduce the energy used and minimize the effect of heat to the polymer that might be can alter or damage the polymer.

3.2 Micro structure of Polymer Modified Bitumen Emulsion:

Forbes et. al. (2001) studied Micro structure of polymer modified bitumen emulsion. The bitumen used in this study was 180/200-penetration bitumen refined from Middle Eastern crude. A latex elastomer polymer was used to modify the bitumen at a concentration of 3% solids by weight of bitumen. Four emulsions consisting of bitumen, water, polymer and emulsifier were prepared using a Charlotte G-3 colloid mill operating under atmospheric pressure. The polymer was added by four different methods: (1) pre-blending the polymer into the bitumen at 180°C for 1 hour before emulsifying; (2)co-milling the latex polymer through the mill with the bitumen and emulsifier solution phases; (3)adding the latex polymer into the emulsifier and water solution; (4) post-adding the latex polymer to the prepared emulsion. A quaternary ammonium slow set cationic emulsifier was used to stabilize the bitumen droplets. The solids content of the emulsions was 62%.

From the study, it can be concluded that, Cationic bitumen emulsion binders containing polymer latex were investigated using confocal laser scanning microscopy, which proved to be a useful technique for this application. The emulsion binder

films were studied after evaporation of the emulsion aqueous phase. It is shown how the structure and distribution of the polymer varies within the bitumen binder depending on latex addition method, and that the structure of the binder remains intact when exposed to elevated temperature. It is also shown how the polymer elongates under stress to improve the bitumen binder resistance to deformation which allows increasing strength of mix.

It was found that the polymer dispersion within a mono phase emulsion binder (polymer is blended into the bitumen before the emulsifying process) is distinctly fine throughout the bitumen. However, the bi-phase emulsion binders (produced by either post adding the latex to the bitumen emulsion, adding the latex into the emulsifier solution phase before processing or co-milling the latex with the bitumen, water and emulsifier) resulted in a network formation of bitumen particles surrounded by a continuous polymer film. This difference in polymer dispersion and binder structure requires further investigation to determine if there is a significant effect on binder performance. The results in this study show that emulsified binders appear to have a more homogeneous distribution of polymer compared to hot polymer-modified binders, and therefore have greater potential for consistent binder cohesion strength, stone retention and consequently improved pavement performance & ultimately enhance the properties of bituminous mix.

3.3 Cold Mix Bitumen:

IRC: SP: 100, (2014) specified the performance requirements of cold mix. A cold mix is defined as a mixture of bitumen emulsion and aggregate that is mixed together at ambient temperature. The cold mix should be designed to meet the performance requirements which include workability, coating, strength development, and other applicable targets. The important elements for design of cold mix are, a) Coating: The emulsion should have ability to coat the aggregate without balling of fines. b) Workability: The mixture must maintain its workability during production, laying etc. c) Run-off: The design should ensure that emulsion run-off from mixture will not occur. d) Aggregate quality: The sand equivalent value test shall be carried out to ensure that clay content is not in excess. e) Bitumen content: The amount of residual bitumen required in the mix is determined based on the surface area of the aggregate. f) Moisture susceptibility: For moisture susceptibility of the mix to intrusion of water, boiling or immersion tests may be used. g) Strength: It can be determined using Marshall Stability Test.

The different types of cold mixes which may be used for construction and maintenance of roads are: A) Cold Mix Bituminous Macadam: It shall involve construction of one or more courses of compacted mixture prepared with bitumen emulsion and mineral aggregate, laid immediately after mixing to required grade and camber using appropriate machinery and used for construction of bituminous base course and for strengthening of flexible pavements. B) Cold Mixed Semi Dense Bituminous Concrete: It is a continuously graded mix, which can be used as binder course or wearing course in a flexible pavement & shall consist of coarse aggregate, fine aggregate and filler in suitable proportion

mixed with sufficient quantity of mixing water and cationic bitumen emulsion. The optimum bitumen emulsion content shall be arrived at by Marshall method of mix design worked out in the laboratory and by using SS-2 grade of cationic bitumen emulsion. C) Bituminous Cold Mixes (Including Gravel Emulsion): This includes providing cold mix consisting of mixture of unheated mineral aggregate and bitumen emulsion, laid in a single layer of 25-75 mm.

3.3.2 Mix Design Procedure for Cold Mix Asphalt (CMA):

Mix design for CMA from most of methods is mainly composed of determining the following items: charge compatibility of emulsion-aggregate system (coating), optimum moisture content at compaction, optimum residual bitumen content and structure performance. It is necessary to examine coating as part of the materials selection process to prevent moisture damage as discussed previously. Current research suggests a minimum threshold of 90% coating for surface courses. Results of trial compactions found that both moisture content and residual bitumen content have significant effects on density, rate of curing and performance.

The mix design procedure for CMA commonly consists of several steps including: coating evaluation, mixing and compaction, curing, volumetric analysis and performance testing. In these procedures optimum emulsion content is determined through volumetric analysis or based on mixture performance test results.

3.4 Benefits of Cold mix process:

J. Keith Davidson et. al., (2012) have described the benefits of using cold mix processes are as follows: production facility, placement operation, products available, engineering properties and energy efficiencies. The production facilities to manufacture these processes have high production. These plants are self-contained, extremely mobile and can be set up rapidly. The mixes can be placed many different ways. A self-propelled travel plant (Midland Mix-paver) can be used or the mix can be placed using a grader. The use of conventional hot mix spreaders is very common. For many of the processes the compaction does not have to be done right away.

The various types of cold mixes can be manufactured using many different types of bitumen emulsions. The emulsion can be tailor-made for a specific material or situation. Each job is unique and pre-engineering is required. The mixes can be used for a specific engineering property. The OGEM is an excellent mix to use where the subgrade is not in the best of condition. Because of its unique self-healing property and capability to withstand high deflections the OGEM is ideally suited.

The cold mix process is very energy efficient. The amount of energy to produce the mix is very low compared to the other road construction processes. There are no concerns about smog days where hot mix production is not allowed. There is typically less fugitive dust present in the air because the aggregate does not have to be dried and the damp aggregate encapsulates all the dust particles.

4. Experimental study of modified Cold Mix

In the study, semi dense graded cold mixes were prepared. Selection of materials and aggregate gradations was as per IRC specifications. Bitumen emulsion of SS2 grade was used & tested as per specifications. PVC powder was used as modifiers. For compaction of cold mixes, Marshall compaction method is followed. For semi dense graded cold mixes (SDCM), mixes are designed as unmodified as well as modified mixes.

The overall methodology of experimental program is described as follows.

- 1) Preparation of test samples
- 2) Testing program
- 3) Comparison of results of all cases
- 4) Conclusion

The experimental study was carried out in 2 phases:

- 1) Preparation of semi dense graded cold mix with cement but without modifier,
- 2) Preparation of semi dense graded cold mix with cement and PVC powder as modifier.

4.1 Material:

In this study 7 to 9 percent of bitumen emulsion is used with 2% of cement as an additive & appropriate percentage of modifiers i.e. Polyvinyl chloride (PVC) powder.

1) Aggregates: For preparation of semi dense graded cold mixes (SDBC), aggregate gradation were taken as per MoRTH (2001) and IRC:SP:79 (2008) specifications. Coarse Aggregate were collected from a local source at Taloja. Its specific gravity was found to be 2.73 as per IS: 2386 (Part-III) procedures. Standard test was conducted to determine some other physical properties.

Fine Aggregate consisted of stone crusher dusts were collected from a local crusher. Aggregates with fractions passing 4.75 mm and retained on 0.075 mm IS sieve were used as fine aggregates. Its specific gravity was found to be 2.60 as per IS: 2386 (Part-III) procedures.

2) Filler: stone crusher dusts were collected from local market. Specific gravity for stone crusher dusts 3.07 & Ordinary Portland cement 53 grade 2% by the total weight of aggregate.

3) Binder: Cationic slow setting (SS2) Bitumen emulsion collected from IWL (India) Ltd. to prepare the samples.

4) Modifiers: Modification of bitumen mix was carried out by adding Polyvinyl Chloride (PVC) purchased from V. K. Traders, Mumbai.

Polyvinyl Chloride having origins like- mineral water bottles, credit cards, toys, pipes and gutters, electrical fittings, furniture, folders and pens, medical disposables etc.



Figure1: PVC powder

4.2 Procedure for preparation of cold mix sample:

1. The dry aggregate was blended into 1200g batches by combining the different aggregate sizes to the desired gradation.
2. The aggregate was used cold (at room temperature)
3. The moisture content was added to the aggregate and mixed thoroughly. The mix was left for 10-15 minutes at room temperature before adding bitumen emulsion.
4. The bitumen emulsion with different percentage added to the wet aggregate and mixed thoroughly for about 2 minutes. The suitability of the mix and degree of coating was then evaluated.
5. After mixing the mixture was kept in oven at 40° C for 72 hours. At the end of 72 hours the specimen were taken out from the oven and poured into the cold pre oiled Marshall mould.
6. The compaction of the mixture was done by the Marshall Compaction hammer on each side of specimen 50 blows.
7. The prepared samples were extruded after 24 hours.

4.3 Marshall samples of Mix:

Semi dense graded mixes are mixes in which the residual bitumen content is between 4% to 8% by the weight of the mix. The mix design involves trial and error method to achieve optimum emulsion and water content. After analysis of tests for various percentages of bitumen emulsion, optimum emulsion percentage can be determined.

Marshall test specimens in triplicate were prepared with different binder content (bitumen emulsion). Specified graded aggregates were blended to achieve standard dense graded bitumen mix. Graded aggregates were moistened with optimum water (3.0%) uniformly. Bitumen emulsion (7%) and cement (2%) were then added to wet aggregates and mixed for 2 minutes for uniform binder coating. The cold mix was aerated on a sieve for 3 hours. The cold mix was then transferred in to Marshall mould with filter paper on base plate and compacted with 50 blows of Marshall hammer on both faces.

Similarly, Marshall specimens were prepared with optimum water content and other bitumen emulsion contents (8% and 9%). Marshall specimens were extracted from the mould after 24 hours. Specimens were then cured in air oven at 40°C for 72 hours. Marshall specimens were then subjected to different

tests such as bulk density, stability and flow value. Marshall stability and flow value were determined in dry state at 25°C. Different properties of mixes were determined and other parameters like void content, voids filled by binder were calculated.

By keeping the aggregate gradation, optimum water content & optimum bitumen content constant, Marshall specimens were prepared with addition of Polyvinyl Chloride (PVC) (4%, 4.5%, 5% 5.5%, 6%) in mix following the same procedure.

4.4 Marshall Test:

It uses standard specimens 63.5mm in height and 101 mm in diameter. The test specimens are prepared on standard Marshall mould by compaction, by giving 50/75 blows on both side of specimen using standard test hammer, for pavements design for medium/heavy trafficked pavement respectively. In the Marshall test method of mix design three compacted samples are prepared for each binder content. At least four binder contents are to be tested to get the optimum binder content. In present study, we have adopted binder content as 7% to 9% of weight of mix. All the compacted specimens are subject to the following tests: bulk density determination, stability and flow test and density and voids analysis. The bulk density of the sample is usually determined by weighting the sample in air and in water.

In conducting the stability test, the specimen is immersed in a bath of water at a temperature of 60°C for a period of 30 minutes. It is then placed in the Marshall stability testing machine and loaded at a constant rate of deformation of 5 mm per minute until failure. The total maximum in kN (that causes failure of the specimen) is taken as Marshall Stability. Flow Value is the amount of deformation in units of 0.25 mm that occurs at maximum load is recorded as Flow Value.

4.5 Indirect Tensile Strength Test:

Indirect tensile test is used to determine the indirect tensile strength (ITS) of bituminous mixes. In this test, a compressive load is applied on a cylindrical specimen (Marshall Sample) along a vertical diametrical plane through two curved strips which radius of curvature is same as that of the specimen. A uniform tensile stress is developed perpendicular to the direction of applied load and along the same vertical plane causing the specimen to fail by splitting. This test is also otherwise known as splitting test. This test can be carried out both under static and dynamic (repeated) conditions. The static test provides information about the tensile strength, modulus of elasticity and Poisson's ratio of bituminous mixes. The static indirect tensile strength test has been used to evaluate the effect of moisture on bituminous mixtures.

Static indirect tensile strength test was conducted using the Marshall test apparatus with a deformation rate of 50 mm per minute. A compressive load was applied along the vertical diametrical plane and a proving ring was used to measure the load. A perspex water bath (270mm × 250mm × 195mm) was prepared and used to maintain constant testing temperature.

Two loading strips, (75mm × 13mm × 13mm), made up of stainless steel were used to transfer the applied load to the specimen. The inside diameter of the strip was same as that of a Marshall sample (101 mm).

The sample was kept in the water bath maintained at the required temperature for minimum 30 minutes before test. The perspex water bath maintained at the same test temperature was placed on the bottom plate of the Marshall apparatus. The sample was then kept inside the perspex water bath within the two loading strips. Care was taken to place the sample centrally along its vertical diametrical plane. A loading rate of 50 mm/minute was adopted.

4.6 Performance evaluation of semi dense graded cold mix (SDCM) with 2% cement:

Samples were prepared for optimum water content (3.0%) for prewetting of aggregates, binder content (7%, 8%, 9%), cement as additive (2%) with coating test & stability results.

The properties that are of interest include the theoretical specific gravity (Gt), the bulk specific gravity of the mix (Gm), air voids % (Vv), volume of bitumen % (Vb), void in mixed aggregate % (VMA) and voids filled with bitumen % (VFB).

4.6.1 Evaluation of SDCM with 2% cement:

The test results of samples which were produced by Marshall compaction as per the adopted design procedure are shown below in Table 4.1

Table 4.1: Compositions of Semi Dense Graded Cold Mix with cement 2%

Properties	Bitumen content		
	7%	8%	9%
Bitumen residue, %	4.41	5.04	5.67
Bulk density, g/cc	2.40	2.39	2.37
Volume of aggregate, %	79.85	79.81	79.10
Volume of binder, %	6.74	7.71	8.42
Air Voids, %	5.20	4.79	3.89
Voids in mineral aggregate (VMA), %	14.2	15.1	14.8
Voids filled with binder (VFB), %	76.65	79.92	81.89
Stability, kg at 25°C	422	476	391
Flow value, mm	4.96	5.32	5.68
Indirect Tensile Strength (kPa)	540	553	535

As per test results properties of semi dense cold mix with cement as additive can be summarized as:

- a. Effect on Marshall Value: Maximum Marshall Satiability Load of 476 kg has been obtained from the Marshall test done for the SDCM with a cold mix content of 8%.
- b. Effect on Density: The value of Maximum Density Obtained with 7% cold mix content is 2.42 gm/cc.
- c. Effect on Air Voids: At cold mix content of 7% the value of minimum air void content is obtained is 4.96%.

d. Optimum binder content: The optimum binder content is the average of Maximum Marshall Stability load, maximum density, and minimum air voids at cold mix content i.e. 7.33%.

4.7 Performance evaluation of semi dense graded cold mix (SDCM) with cement & PVC powder:

Various samples were prepared considering optimum water content (3.0%) for pre wetting of aggregates, optimum binder content (7.33%), cement as additive (2%) & PVC powder (4%, 4.5%, 5.0%, 5.5%, 6%) with coating test & stability results.

4.7.1 Evaluation of SDCM with 2% cement & PVC powder:

The test results of samples which were produced by optimum water content (3.0%) for prewetting of aggregates, optimum binder content (7.33%), cement as additive (2%) & PVC powder (4%, 4.5%, 5.5%, 6%) Marshall compaction as per the adopted design procedure are shown in Table 4.2

Table 4.2: Compositions of SDCM with cement 2% & PVC powder

Properties	PVC powder		
	4%	5%	6%
Bulk density, g/cc	2.22	2.29	2.36
Volume of aggregate, %	79.82	79.75	79.71
Volume of binder, %	6.35	6.85	7.32
Air Voids, %	3.96	3.70	3.21
Voids in mineral aggregate (VMA), %	13.86	14.86	14.20
Voids filled with binder (VFB), %	77.80	78.32	80.12
Stability, kg at 25°C	562	590	553
Flow value, mm	5.21	5.86	5.68
Indirect Tensile Strength (kPa)	598	621	535

As per test results properties of semi dense cold mix with cement as additive can be summarized as:

- a. Effect on Marshall Value: Maximum Marshall Satiability Load of 590 kg has been obtained from the Marshall test done for the semi dense cold mix having optimum bitumen content of 7.33%, & PVC content of 5%.
- b. Effect on Density: The value of Maximum Density Obtained with 7.33% cold mix content & PVC content of 6% is 2.36 gm/cc
- c. Effect on Air Voids: At cold mix having 6% PVC content value of minimum air void content is obtained is 3.21%.

4.8 Comparison of SDCM with cement and PVC powder:

As per evaluation of test result, property comparison between cold mix with cement as additive and cold mix with cement as additive and Polyvinyl chloride (PVC) powder as modifiers, stability and strength is increased @ 20% by use of PVC as modifier. The property comparison can be summarized as per table 4.3

Table 4.3: Property comparison of cold mix with cement and PVC powder

Properties	Cement 2%	PVC powder 5%
Bulk density, g/cc	2.39	2.29
Volume of aggregate, %	79.81	79.75
Volume of binder, %	7.71	6.85
Air Voids, %	4.79	3.70
Voids in mineral aggregate (VMA), %	15.1	14.86
Voids filled with binder (VFB), %	79.92	78.32
Stability, kg at 25°C	476	590
Flow value, mm	5.32	5.86
Indirect Tensile Strength (kPa)	553	621

5. Conclusion

The results of the experimental observation show that the performance of Modified SDCM is better than that of unmodified bitumen cold mix under the following considerations.

1. Polymer modified bitumen cold mix is found to have a high elastic recovery (79%) as compared to unmodified cold mix.
2. When Polymer was used Marshall stability of the mix increases by @ 20%.
3. The rutting resistance of the polymer modified cold mix is significantly higher.
4. The indirect tensile strength of the mix with polymer modifier is 20% higher than unmodified cold mix at 30 °C.

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