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A Study On Performance And Design Of Cold Mix Asphalt On Effect Of Mix Parameters

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ABSTRACT: Hot mix technology has seen significant advances through many research programs. Cold mix technology is lagging behind in both research and application fields which is quite observable in a developing country like India. This is the primary motivation underlying selection of this cold mix technology as the present research area. Besides, it has environmental and economical advantages over hot mixes. Till now there is no universally accepted cold mix design procedure. In the absence of uniformity in the laboratory cold mix design procedures followed by different researchers/agencies/organisation, it is difficult to form reliable correlations and to have a comparative study between experimental results reported by them. Hence the objectives of this project work are aimed to select important mix parameters and determine their effects on performance of Cold Mix Asphalt (CMA). The mix parameters selected for the present work are
(i) Method of compaction, (ii) level of compaction, (iii) additives and (iv) aggregate gradation. The first three parameters are selected for their importance as presented in a number of previous research works. The last one has been selected as nowhere in literature much attention has been paid to the aggregate gradation which is the skeleton of the compacted mix. It is observed that Bailey method for gradation selection is the only method for HMA/SMA mixture which analyses the aggregate gradations both considering the blend by volume as well as blend by weight. In this study Bailey's concept has been considered for cold mix design. All the mix parameters have been selected to assess the effect on Marshall Properties of CMA mixture. Initially a suitable experimental methodology has been prepared and then the effects of selected mix parameters on performance of compacted mix are studied. Finally a comparative study for above results has been done on basis of the Marshall Stability and air void content of the cold mix. Considering all the selected mix parameters it is observed that only in case of gyratory compaction the adequate air void range (3 to 5 %) in cold mixes can be achieved. Besides, though each and every parameter has contributed to increase the Marshall Stability of cold mixes, cement and developed gradations have shown more significant increase in stability of cold mixes.

Keywords: Cold mix compaction, Additives, Bailey concept, Aggregate gradation, Cold mix design.

Introduction

Overview

Several ambitious road construction plans and activities primarily involve bituminous pavements with hot mix technology. Hot mix technology which is a very conventional method for road construction, has structurally satisfied the performance requirements over many years. The procedures generally followed by the hot mix technology are : heating of binder and aggregate, mixing, tack coating, laying of mix followed by the

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compaction process everything done at high temperature in a range of 120ºC to 165ºC temperature. Though performance wise this has been the most suitable for pavement structures, but their high use have several drawbacks like environmental degradation, high energy consumption, increase in carbon footprint, low output for mix production, low laying work in rains and cold weather, limited construction period in a year, oxidative hardening of binder, health and safety hazard to labour (Pundhir et al., 2012). Besides this, in some North and North Eastern parts of India like Jammu and Kashmir, Assam, Manipur, Meghalaya, Arunachal Pradesh and others, rural road projects involving several lakhs and crores of rupees are beyond time. Due to topographical and weather constraints, it is difficult to work with hot mix technology in such hilly regions, heavy rainfall and forest zones. So, it is desirable to find out a suitable alternative for hot mix technology.

Statement of the Problem

Though the emulsion based cold mixes overcome hot mix problems, they have attracted little attention and considered inferior to hot mix as structural layers due to their less satisfactory performance. Thanaya et al. (2009) reported some major problems with cold mixes such as high air-void content in the compacted mixes, weak early life strength due to pre-wetting water, long time required to achieve fully cured samples for maximum performance. In addition to this the pre-wetting water in cold mix which is considered as an important part of the process, becomes a problem since inhibiting compaction. Various researches have been carried out to improve the properties of cold mix till now. But still they are very few in comparison to the same in case of hot mix.

Objectives and Scope

The broad research objectives of the study are described below.

- To select mix parameters and evaluate their effects on properties of cold mix asphalt (CMA) mixtures.
- To study and analyse the effects of aggregate gradation on properties of CMA mixtures.
- To recommend some most desired mix parameters for consideration in cold mix design from performance point of view.

Experimental Investigations

Introduction

This chapter highlights the experimental works conducted throughout the project. It presents the methodology of experimental program to accomplish the overall framework of the present study stated in section 1.3 and also deals with experiments carried out on the materials and detailed test procedures for cold mixes.

Methodology of Experimental Program

In the study, both dense (BC) and gap (SMA) graded cold mixes were prepared. Selection of materials and aggregate gradations was as per specifications specified later. For compaction of cold mixes, both Marshall compaction and gyratory compaction were followed. MORTH (2001) specification, Asphalt Institute Manual Series 14 (1997) and the recommendations provided by Thanaya (2007) were taken in to consideration for the selection of cold mix design procedure. Effects of compaction level in both methods of compaction as well as the effects of additives such as cement, lime and fly ash on properties of cold mixes were observed. For both types of cold mixes (BC, SMA) six numbers of modified aggregate gradations were designed within the initially adopted gradation limits. These six gradations were produced by combining two values (maximum, minimum) of CA ratio and three values (maximum, minimum, middle) of filler quantities.

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Selection of Cold Mix Design Procedure

After the comparative study on the design procedures summarized in table 2.1 and considering the design requirements as per MORTH provided in table 2.2., the suitable cold mix design procedures followed in the present study for both method of compaction are briefly illustrated in table 3.1. There are few differences between the adopted design procedures for both method of compaction (Marshall, gyratory) and the concept behind this is explained later in result and discussion sighted in chapter four.

Table 3.1 CMA design procedure for present study

S.No	Marshall compaction	Gyratory compaction
1	Aggregate gradation (As per specifications)	Aggregate gradation (As per specifications)
2	IRAC and IEC (As per MS 14 formula)	IRAC and IEC (As per MS 14 formula)
3	OPWC (Coating Test)	OPWC (Coating Test)
4	50 blows of compaction level (as per MORTH)	Compaction Level i.e. number of gyrations to achieve air void target
5	OTLC (Dry Stability Test)	(Dry Stability Test)
6	ORAC (Soaked Stability Test)	OTLC (Dry Stability Test)
7	Retained Stability (Dry Stability	ORAC (Soaked Stability Test)
8	Test at ORAC)	Retained Stability (Dry Stability Test at ORAC)
9		Increase in compaction Level to achieve air void target if required (Dry Stability Test at ORAC)

Materials Used

Aggregates

For preparation of cold mixes, two types of aggregate gradations such as dense gradation (BC) and gap gradation (SMA) were taken as per MORTH (2001) and IRC:SP:79 (2008) specifications and was given in table 3.2 and table 3.3 respectively.

Coarse Aggregates: Raw materials consisted of stone chips were collected from a local source. Aggregates up to 4.75 mm ARE sieve size were used as coarse aggregate. Its specific gravity was found to be 2.75 as per IS: 2386 (Part-III) procedures. Standard test was conducted to determine some other physical properties and is summarized in table 3.4.

Fine Aggregates: Raw materials 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 sieves were used as fine aggregates. Its specific gravity was found to be 2.62 as per IS: 2386 (Part-III) procedures.

Filler

Raw materials for stone crusher dusts were collected from a local crusher while fly ash, lime and Portland slag cement (Grade 43) were collected from local market. Materials passing 0.075 mm ARE sieve was used as filler material. Specific gravity for stone crusher dusts, fly ash, lime and cement were found to be 2.7, 2.2, 2.3 and 3.07 respectively.

Binder

Cationic medium setting (CMS) Bitumen emulsion collected from the reliable

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source was used in this investigation to prepare the samples. Its residual asphalt content was found to be 65.4%. Some of its important physical properties are given in table 3.5.

Preparation and Testing of samples

The mixes were prepared according to the cold mix design procedure given in table 3.1. The detailed justification behind the adopted design concept and its validation is given in chapter four. The whole process is illustrated in the next paragraphs.

1. The validation of design procedure was accomplished by taking two sets of IRAC for Marshall Compaction method, one IRAC value was taken as per given formula and another one was taken arbitrarily. Once the efficiency of the empirical formula was proved, then the requirement of OTLC calculation was studied for both compaction methods. Initially 40, 80, 100 and 120 numbers of gyrations were used to determine the required compaction level. These were taken from the literature review. Then the optimum residual asphalt content (ORAC) was found out for both aggregate gradations using stone crusher dusts as filler material.
2. In case of Marshall Compaction, the effect of compaction level on properties of cold mixes was studied at ORAC only. The number of blows was varied from 50 to 75 blows per each face of compacted specimen. In case of gyratory compaction 40, 80, 100, 120 numbers of gyrations were tried at IRAC only.
3. In next stage cement, lime and fly ash were substituted separately for stone crusher dusts in the mix composition that was found for Marshall Compaction at ORAC only. In case of dense gradation (BC) the substitution was done in a range of 1 to 5 % with 1 % increment and in case of gap gradation (SMA) 2, 4, 5, 6, 8 and 10 % substitutions were done. In this study the stone crusher dust was used as the primary filler material while the secondary filler materials (cement, lime, fly ash) were used as additives. Instead of finding ORAC in case of all additives, the study aimed to observe the effect of different composition at the obtained ORAC to maintain the consistency in the study.

Laboratory Tests

Marshall Test

In this method, the resistance to plastic deformation of a compacted cylindrical specimen of bituminous mixture is measured when the specimen is loaded diametrically at a deformation rate of 50 mm per minute. There are two major features of the Marshall method of mix design. (i) density-voids analysis and (ii) stability-flow tests. The Marshall stability of the mix is defined as the maximum load carried by the specimen at the specified standard test temperature. The flow value is the deformation that the test specimen undergoes during loading up to the maximum load.

The apparatus consists of mould assembly, sample extractor, compaction pedestal and hammer, breaking head, loading machine, flow meter, water bath. 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. 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. It may be also calculated using the weight in saturated surface dry condition.

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The formulas as suggested by Thanaya (2007) have been followed in the present work.

Gyratory compaction

The Gyratory Compactor used in the present study was entirely developed and manufactured by Matest to simulate and reproduce the real compaction conditions under actual road paving operations, hence determining the compaction properties of the asphalt. Such compaction is achieved by combining the rotary action and the vertical resultant force applied by a mechanical head. The Compactor comprises a highly rigid steel frame ensuring excellent angle control. Load is applied by an electro-pneumatic cylinder, servo-controlled by a precision pressure regulator; the height is measured by a linear transducer. Gyratory motion is generated by an eccentric high precision system allowing an easy set up with precision and constant angle of gyration. The rotation speed is controlled by an inverter through on board computer control. Using the proper perforated mould, the Compactor is able to run tests on cold mix asphalt. The acquired results are also employed in the investigation of volumetric and mechanical characteristics of the asphalt mix.

The parameters used in the present study are the 100 mm diameter mould, 1.25° gyratory angle 30 rpm gyration rate, 4.711kN vertical load on 100mm diameter specimen. The vertical load on the specimen is automatically controlled and adjusted by the electronic system.

Static 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.

In the present study 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. The load was applied and the failure load was noted from the dial gauge of the proving ring. The tensile strength of the specimen was calculated by using the formula given in ASTM D 6931 (2007) and mentioned in equation 3(vi).

Static Creep Test

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For static creep test samples were prepared at their OTLC and ORAC. As per TEX-231-F (2005) static creep test procedure the test was conducted and it consisted of two stages. In first stage a vertical load of 0.55 kN was applied for 60 minutes. The deformation was registered during 10 minutes intervals using a dial gauge graduated in units of 0.002 mm and it was able to register a maximum deflection of 5 mm. Secondly, the load was removed and its deformation was registered during next 10 minutes at 5 minutes interval of time. Test temperatures of 400, 500 and 600 were applied in the present study. Finally a graph between time and deformation was plotted.

Analysis of Results

Introduction

The results obtained for compacted samples to analyse the effect of test parameters are discussed in this chapter. Attempt has been taken to justify the adopted design procedure and ORAC value is found out. The effects of additives, method and level of compaction on the performance of cold mixes have been studied. After constructing a spreadsheet the existing aggregate gradations are improved by using Bailey concept for aggregate packing. The performance of all the developed gradations has been observed and compared with the initial gradations

Dense graded cold mixes

As per the adopted design procedure given in table 3.1, Samples were produced by Marshall compaction. The test results are summarized in table 4.1 and illustrated in figure 4.1 to figure 4.2.

Table 4.1 Optimum compositions of dense graded cold mixes

IRAC by Empirical formula	IRAC by arbitrary value
IRAC=6%	IRAC=4%
IEC = 9.17 %	IEC=6%
OPWC=3%	OPWC=4%
OTLC = 6.17 %	OTLC = 7.07 %
ORAC = 4.6 %	ORAC = 4.6 %
Soaked Stability = 5.88 kN	Soaked Stability = 3.19 kN
Dry Stability = 6.28 kN	Dry Stability = 3.45 kN

It should be noted that both the results of dry stability and soaked stability given were the values obtained at ORAC value.

- Determination of OTLC values:

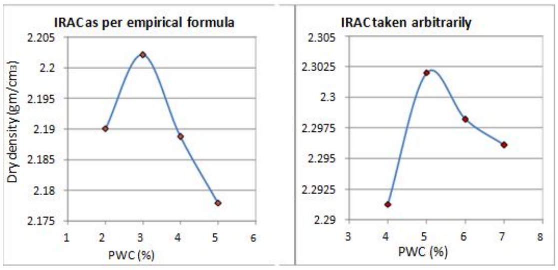

Figure 4.1 OTLC determination for dense graded cold mixes

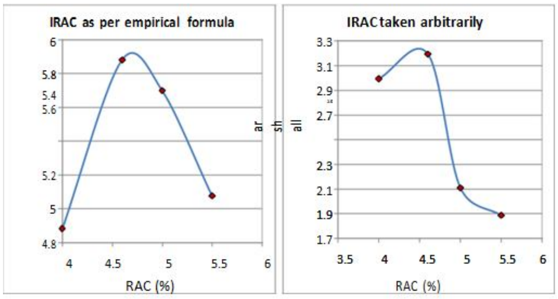

Figure 4.2 ORAC determination for dense graded cold mixes

Gap graded cold mixes

The test results for gap graded cold mixes are summarized in table 4.2 and illustrated in figure 4.4 to figure 4.5. It should be noted that both the results of dry stability and soaked stability given were the values obtained at ORAC value.

Table 4.2 Optimum compositions of gap graded cold mixes

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IRAC by Empirical formula	IRAC by Arbitrary value
IRAC=7%	IRAC = 4.6 %
IEC = 10.7 %	IEC = 6.5 %
OPWC=3%	OPWC=5%
OTLC = 8.7 %	OTLC = 9.25 %
ORAC = 5.5 %	ORAC = 5.5 %
Soaked Stability = 3.46 kN	Soaked Stability = 3.1 kN
Dry Stability = 3.67 kN	Dry Stability = 3.21 kN

Determination of OTLC values:

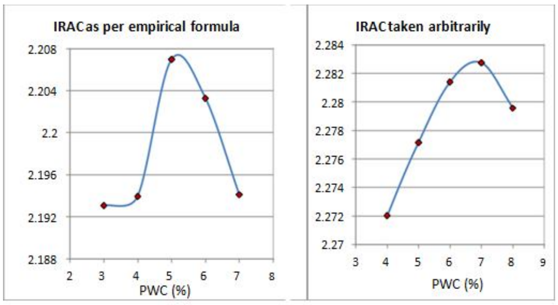

Figure 4.4 OTLC determination for gap graded cold mixes

Determination of ORAC values:

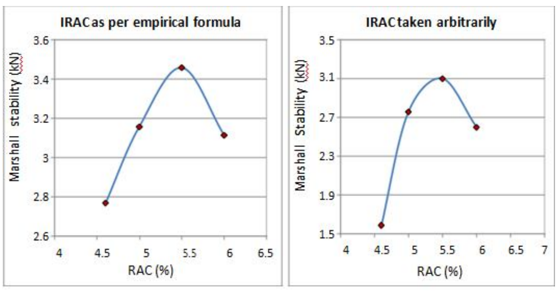

Figure 4.5 ORAC determination for gap graded cold mixes

Comparative study between dense and gap graded cold mix

It was observed that performance of dense graded mix (Cold Mix D) was superior than gap graded mix (Cold Mix G) in every aspect except in case of the stability loss value which was lesser for Cold Mix G.

Table 4.3 Design parameters of cold mixes at 50 blows of compaction

Design parameters	Dense graded mix (Cold Mix D)	Gap graded mix (Cold Mix G)	Design requirement
Marshall Stability	5.88 kN	3.46 kN	Min. 2.2 kN
Flow value	3.3 mm	3.4 mm	Min. 2 mm
Stability loss	6.36 %	5.87 %	Max. 50 %
Emulsion content	7% (4.6% ORAC)	8.4% (5.5% ORAC)	7-10%
Air void	8.32 %	9.22 %	3-5%
VMA	14.83 %	16.95 %	Cold Mix D: Min. 14 % Cold Mix G: Min. 15 %

Effect of Additives

Cement, lime and fly ash were substituted for stone crusher dust in the mix composition found for Marshall compacted dense graded and gap graded cold mix at ORAC only.

Dense graded cold mixes

For dense graded cold mix substitution of additives was done separately in a range of 1 to 5% with 1 % increment. The obtained test results are shown in figure 4.7.

It was observed that cold mixes with cement as an additive performed best among all mixes in every aspect. Though mixes with lime and fly ash as an additive had showed greater stability than the

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mixes without additive, but they resulted greater air void content with the increase in percentage of substitution. Besides, lime had improved the mix stability more efficiently than the fly ash, but it also caused higher air void content in compacted mix in comparison to fly ash.

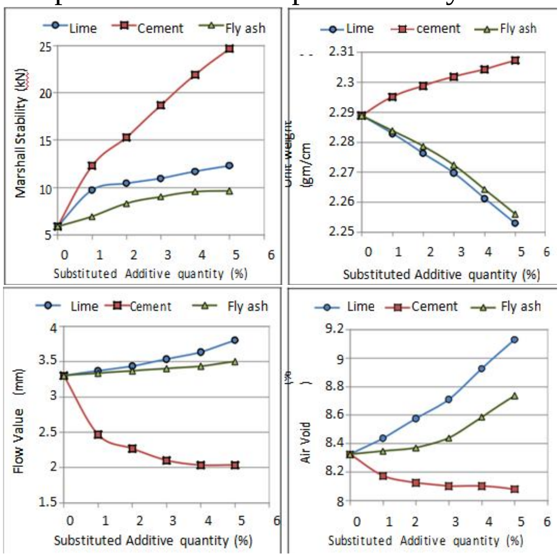

Figure 4.7 Marshall Stability, Unit weight, Flow value and Air void results of dense graded cold mix with additives

Gap graded cold mixes

For gap graded cold mix 2%, 4%, 5%, 6%, 8% and 10 % substitutions of additives were done separately. The obtained test results are shown in figure 4.8.

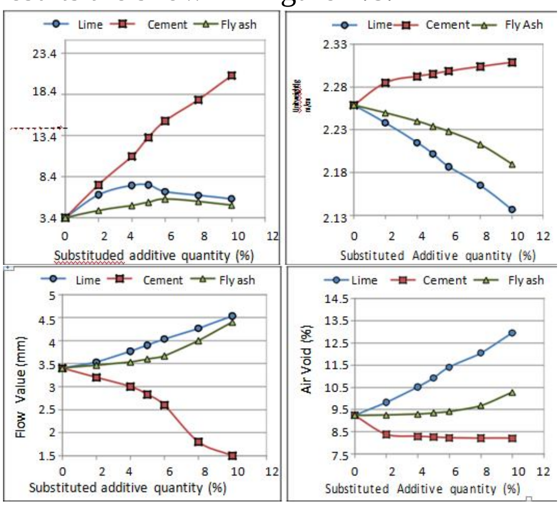

Figure 4.8 Marshall Stability, Unit weight, Flow value and Air void results of gap graded cold mix with additives

Comparative study between dense graded and gap graded cold mixes

The results obtained for Marshall Stability and air void for dense and gap graded cold mix in both method of compaction are summarised in table 4.7.

Table 4.7 Marshall Stability and air void results of cold mixes for Marshall and gyratory compaction

Marshall compaction (50 blows)		Gyratory compaction (40 gyrations)	
Dense graded mix	**Gap graded mix**	**Dense graded mix**	**Gap graded mix**
Marshall Stability = 5.88 kN	Marshall Stability = 3.46 kN	Marshall Stability = 6.02 kN	Marshall Stability = 4.54 kN
Air void = 8.32 %	Air void = 9.22 %	Air void = 4.82 %	Air void = 4.91 %

From the comparative study it was observed that though gyratory compaction method did not show much influence on the Marshall Stability but it was highly effective to reduce the air void content in cold mix asphalt and to get the adequate air void range (3 to 5 %) even at 40 numbers of gyrations.

Effect of Mix Parameters on Cold Mix Asphalt Performance

The effect of mix parameters on Marshall Stability and percentage of air void in cold mixes are shown in figure 4.35 and figure 4.36 respectively.

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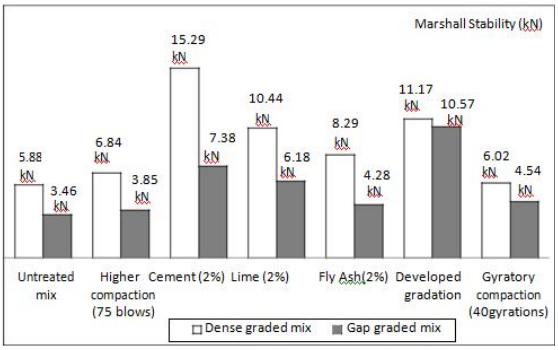

Figure 4.35 Effect of mix parameters on Marshall Stability of cold mixes

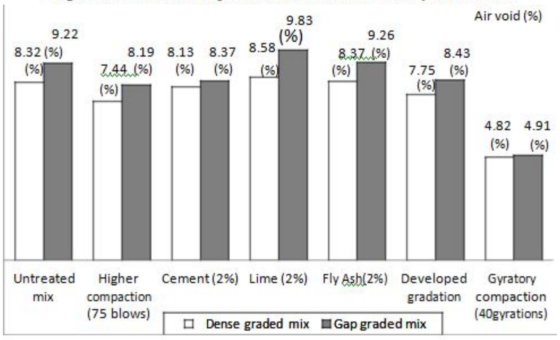

Figure 4.36 Effect of mix parameters on percentage of air void in cold mixes

Summary

In this chapter by using the adopted cold mix design procedure the effects of selected mix parameters on performance of CMA mixtures are studied. Finally a comparative study for above results has been done on basis of the Marshall Stability and air void content of the cold mix. Additive like cement is found to be highly effective as observed in the series of literature. In addition Bailey method is found to be effective in improving the Marshall Stability of cold mixes. It is also observed that the adequate air void range as specified by MORTH (2001) can be achieved by gyratory compacted cold mixes only.

Chapter five presents the summary and conclusions of the project work. It also gives the limitations of present work and recommendations for future research scope in this area.

Conclusions

From the above study following conclusions are drawn based on performance of the cold mix.

- From the limited study it is observed that initial stability of the mix is dependent on optimum total liquid content (OTLC) of the compacted mix. At same binder content higher the total liquid content, greater is the curing time to obtain full strength of the mix. Although achieving OTLC is difficult for field application, it may be applied for laboratory procedures to avoid delay in work process. This concept has supported the adopted design procedure of the present study.
- Increment in the compaction level is found not to be much effective in decreasing the air voids in cold mixes rather it increased the stability loss value in the gap graded mix (SMA) which may be resulted due to the destruction of stone-to-stone contact skeleton at higher compaction level. Besides, higher is the compaction level, greater may be the difficulty in field applications.
- Increase in number of gyrations has resulted in the increased stability and reduced air void content of compacted cold mixes. 40 numbers of gyration has been found to be suitable as at higher level of compaction bleeding phenomenon of binder occurred which may affect the durability of the mix.
- Among the additives, though the stability value has been found to be improved by fly ash, lime and cement, performance of cement modified mix is observed to be superior in every aspect. Comparing lime and fly ash as substituted for filler, greater stability but higher air void content

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is noticed in case of cold mixes modified with lime.

- The Bailey method for gradation selection has been found to be effective for improving the stability of both dense and gap graded cold mixes even without addition of cement.
- In between dense and gap graded cold mixes, though the dense graded mixes has resulted in higher stability value, it has showed lesser indirect tensile strength and higher deformation in comparison to gap graded mix.
- Considering all the selected mix parameters it is noticed that only in case of gyratory compaction the adequate air void range (3 to 5 %) in cold mixes has been achieved. Besides, though each and every parameter has contributed to increase the Marshall Stability of cold mixes, cement and developed gradations has shown more significant effect to increase the stability of cold mixes.

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