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Relation Between Air Voids And Bitumen Content In Bituminous Concrete (BC) Mixes

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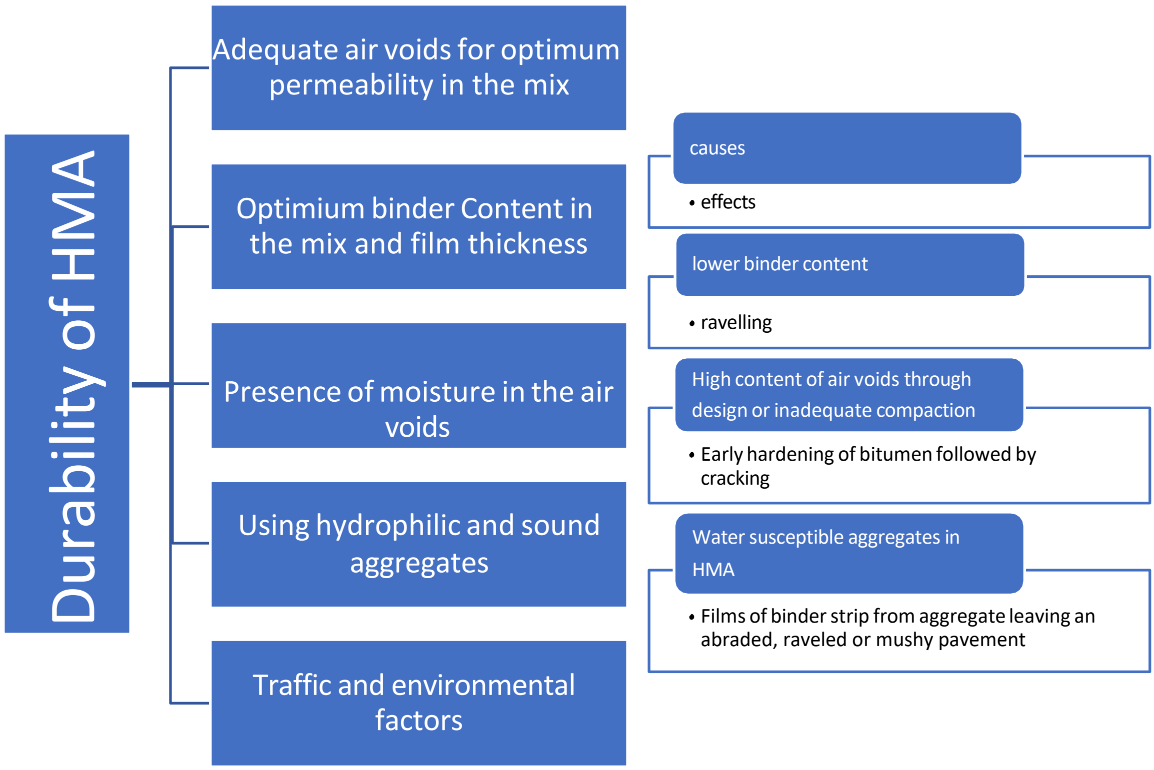
Abstract
Flexible pavement is popular in many countries. Flexible pavement in the form of Hot mix asphalt is a mixture of aggregates, bitumen as a binder and air voids. Many authors have estimated the factors affecting durability of the mix. Durability of HMA is affected by the presence of void system and sensitive to bitumen content. This paper is aiming to find association between content of bitumen and air voids in the bituminous concrete (BC) mixes. The bitumen of Viscosity Grade-30 and aggregates of siliceous sandstone and basalt are used in this study. The samples have been collected from two different sources one from Sheikhpura and other from Mirza chowki for establishment of relationship. It was found that on increase in actual bitumen content the percentage air voids decreases and its vice - versa. It is found that the actual air voids differ than the designed air voids because of difference in the amount of compaction in the field and in the laboratory. So, this difference in percentage air voids is significant and the designed air voids which is essential in Marshall mix design method for better performance in real practice. which indicates towards a requirement of reduction in the minimum bitumen content for BC as described in the MoRTH. As bitumen consumption reduces, the cost will drastically reduce.
Keywords *Hot mix asphalt . Durability . Bituminous concrete mix . Bitumen content . Percentage air voids .*

INTRODUCTION

Flexible pavements exist in large number specially in developing countries. In flexible pavement, bitumen is used as a prime binding material in the uppermost layers. A good riding surface, rapid construction, lower supervision requirement and potential of processed phased construction practices makes it advantageous to other type of pavements (EAPA 2015) [1]. In flexible pavements, bituminous concrete mixes are widely used for the construction of wearing and binder courses. Surface layers of flexible pavements have low durability because of exposure to the environmental loads. The process of degradation of mixes due to moisture present in the void system of mix and the phenomenon is known as 'moisture damage'. Moisture enters into the air voids of bituminous mix layer through various surface discontinuities, edges, seepages and capillary action. This kind of damage generally produces other distress like cracking, rutting, ravelling etc. [2]. Bituminous concrete mixes which are also known as HMA is a mixture of aggregates, bitumen and air voids. The performance of mix is mainly influenced by material properties, nature of traffic, climatic condition and construction technique [3]. One of the important characteristics of HMA pavement is durability, which is the ability to resist against the effect of oxidation in binding material and disintegration of aggregates. It is because of the environmental load or traffic load or consolidation of both. Overall Durability of HMA pavement is influenced by use of insufficient film thickness, use of hydrophobic aggregates and presence of excessive air voids [4,5]. Durability of flexible pavement is distressed with existence of any form of moisture in the air void system of HMA which aggregately affects overall performance of pavements [6].



All these studies suggest that the durability of HMA is an important aspect because overall performance of the mix is associated. Further, it is found that the Durability of HMA is the function of air voids, bitumen content, moisture, nature of aggregates, film thickness, nature of traffic, environmental factors etc. and insufficient use of which leads to failure. Following is the pictorial representation of the function upon which durability of the mix depends and its effect on the performance of the mix.
Willoughby found that the air voids in HMA impacts significantly in terms of long-term attainment of performance in pavement. In detail mixes having either much high or low air voids cause recognize reduction in life of pavement [7]. Goode and Lufsey found that film thickness and air voids are answerable for paying the attention on the performance of HMA [8]. Kumar investigated the impact of film thickness, air voids and permeability on hardening of HMA and found the existence of link between log of permeability and air voids in terms of percentage is linear [9]. Joshi and Patel approaches for functional, economical and secure design criteria in HMA. Meanwhile, the study indicates that the mix must contain adequate amount of air voids in terms to allow good degree of compaction because on application of traffic load it doesn't perform bleeding and remains stable, whereas a decent workability is performed for easy facilitation [10]. Both, Resilient modulus and abrasion loss of the mix exhibit identical pattern when content of air voids is low but at high air voids content mixes show more durability. Also, it is already concluded that the performance of porous asphalt mixes is dominantly affected by air voids in many aspects. After overall analysis for HMA depends upon place of use and its types, there is requirement to create an ease of dependence between bitumen content and amount of air voids. In bituminous concrete mixes air voids consist air spaces between the coated aggregates and compacted bitumen [11].

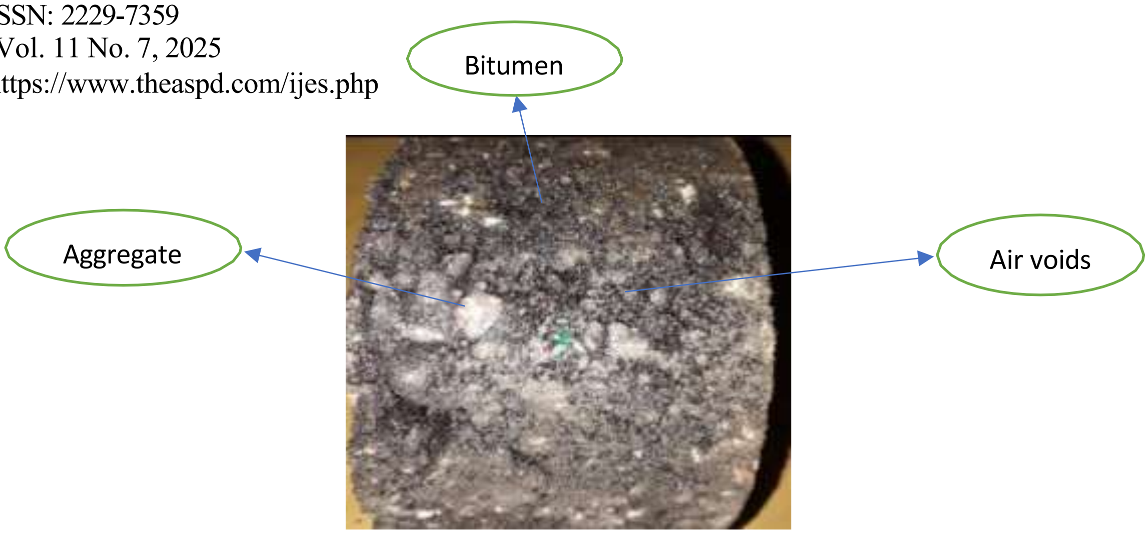


Fig. 1 Sample specimen of BC

Study of Roberts et al. on HMA indicated that air void should be in between 3% to 8% in dense graded mixes during service life and in this area of air voids, mix performs the best in terms of strength, durability, ravelling, rutting, fatigue and moisture damage susceptibility [12]. Air voids in between 3 to 5% results into decent execution in case of dense mixes like bituminous concrete (BC) [13,14]. Girald et al. derived the effect of percentage air voids used for design in Superpave mix in terms of durability and suggests to increase the design air voids from 4% to 5% [15,19]. Eshan et al. found various volumetric parameters which influences the performance of HMA both at laboratory and field which concludes that the bitumen content and its types play an important role on cracking performance. [16,18].

Above study suggests that the air voids and film thickness of bitumen greatly influence the performance of HMA. Moreover, the study indicates towards optimizing the air voids value in terms to improve the durability of the mix. Even in some study air void range is mentioned to concretize the importance of air voids in the pavement performance. Krugler et al. focusses the durability in terms of factor affecting the performance of HMA [5]. Durability enhances due to ease of hardening, brittleness and stripping of bitumen. Both air voids and content of bitumen loudly affect the early hardening of bitumen. [17]. Kamil et al. studied the impact of static and dynamic creep test on the attainment of performance in bituminous mixes and variations in content of bitumen and air voids both are sensitive [18]. Nejad et al. came to a conclusion that the bitumen content is functionally associated with rutting resistance parameter. On increment in content of bitumen, the rutting resistance properties escalates up to a certain limit and declines thereafter due to instability of materials but in case of reduction in air voids initially the rutting resistance boosts up to a certain limit and thereafter starts to decline [19]. Baskandi investigated that the managing properties such as content of bitumen, air voids and degree of compaction in the mix influences the pavement performance in terms of fatigue and rutting behaviour is associated with air voids and bitumen content [20].

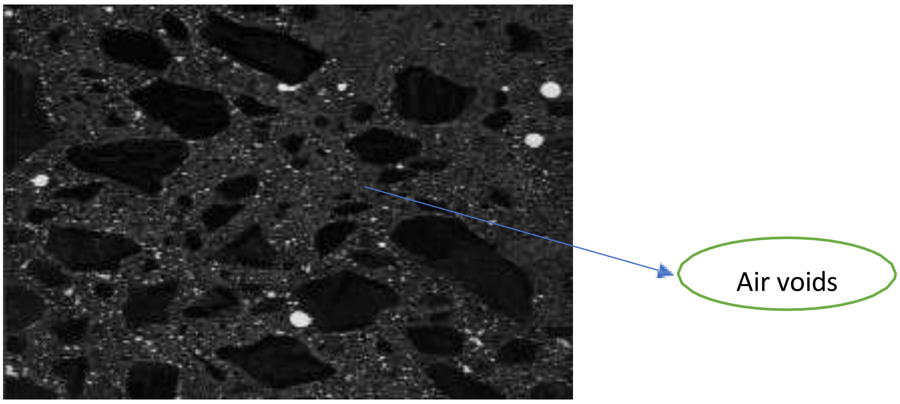


Fig. 2 Pelcon Materials & Testing ApS

Durability in terms of early hardening, brittleness and stripping of bitumen, and rutting and fatigue resistance of the mix is significantly controlled by air voids and bitumen content. Therefore, it is obvious that the role of air voids and content of bitumen in the performance of HMA and it is needed to establish bond between these two controlling parameters of HMA. So, it is essential to know the nature of relation between the air voids and content of bitumen in the bituminous concrete (BC) mix.

Air voids belonging to final in-place and initial in-place are thus calculated by correlating bulk density at field after a long tenure of compaction and just after construction to the theoretical maximum density respectively. As far as air void is concerned, samples that are compacted in the laboratory is intended to achieve final in-place air voids [23]. It is found that during preparation of mix, the initial in-place air voids immediate after compaction is about 7–8% of the theoretical maximum density and in the next 2–3 years of subsequent traffic, the mix solidifies to final in-place air voids of 3–5% for dense graded mixes [24 - 26]. Another study suggests that the mixes which are designed to achieve 4% final in-place air voids and consolidated to 95% initial in-place density as compared to laboratory bulk density resulting into 9% initial in-place density [27]. Moreover, Mixes are placed at much lesser in-place density as compared to theoretical density in Marshall mix design method [22]. Marshall method of bituminous mix design is followed in India as described in Asphalt Institute Manual Series-2 (MS-2) [21].

It can easily be concluded that lower density exhibits the existence of higher air voids. Also, it is found that the initial in-place air voids must be more than the targeted final in-place air voids because initial in-place air voids just after compaction decreases under the traffic load within couple of years after construction. Therefore, it seems essential to focus our study on the content of binder and air voids in the bituminous concrete mixes.

Objective

According to study air voids and amount of bitumen in the mix plays deciding role on the durability of the HMA. The air voids and content of bitumen during construction changes over a course of time that results into a deviation in the actual value and the designed value. Overall objective of this paper is to prepare the sample by collecting raw materials from different source which then undergoes the actual lab and field condition. Meanwhile, our focus must be on relation between the actual content of bitumen and air voids in bituminous concrete mixes.

Methods of testing samples

Total 20 no. of Sample of BC mix collected from the field to evaluate the content of bitumen and air voids. To fulfil the desired objective, it is essential to authorize a relationship between these two parameters. The specimen has been taken during March to May 2024 from Sheikhpura district in the state of Bihar and Mirza chowki, Sahib Ganj district in the state of Jharkhand in India. Traffic operated on the pavement is for very short interval of time in comparison to its design life which is due to keep the effect of traffic negligible. Following are the steps to determine the actual content of bitumen and air voids.

Step 1 Bitumen extraction Test

It has been required to evaluate the actual content of bitumen in the sample specimen of BC.

Wt. of the dry BC sample = 1576.05 gm

Wt. of dry aggregate in BC sample after extraction of bitumen = 1501 gm

Wt. of the bitumen in BC sample = 1576.05 g - 1501 g = 75.05 gm

Actual bitumen content = (75.05/1501) *100% = 5 %

Step 2 Sieve analysis of aggregates collected from source

The aggregates collected from the sample after eradication of bitumen is sieved to evaluate the weight of coarse aggregates, fine aggregates and Stone dust separately which are prime constituent of the mix. The sieve analysis of the dry aggregates has been derived and distribution of grain size is reported in terms of graph for both the sources of Sample Specimen.

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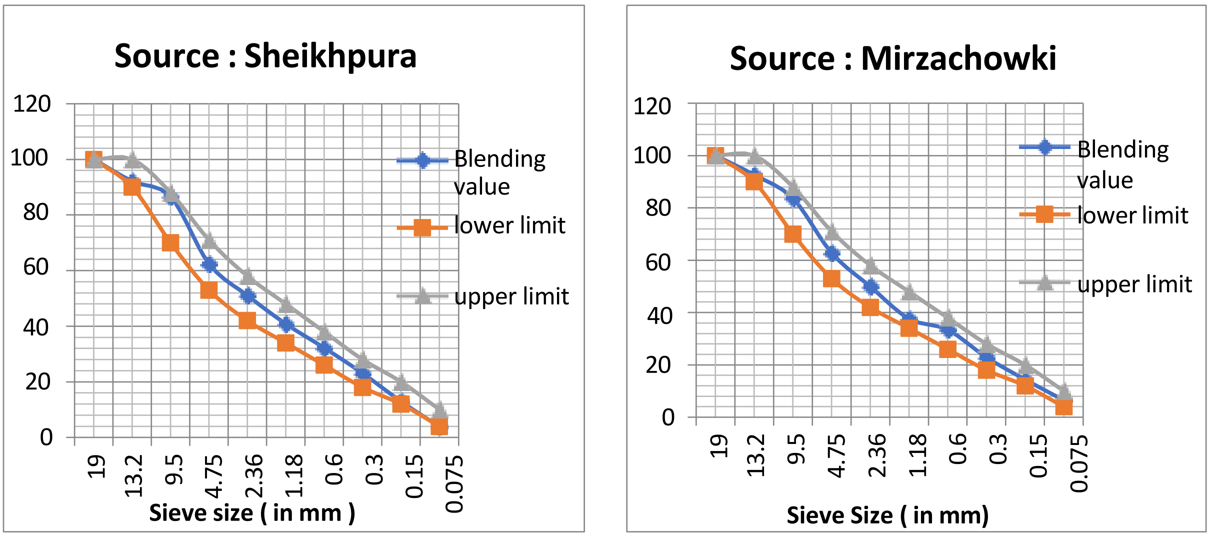


Fig. 3 Gradation of sample aggregates

(a) Sheikhpura (b) Mirza chowki

Step 3 Bulk Specific Gravity Test

One more core has been taken to evaluate the bulk specific gravity of BC (G_m).

Wt. of mix in air (W_m) = 462 gm

Wt. of mix in water (W_w) = 263 gm

Calculate the bulk specific gravity of HMA (G_m) by using the Equation given below.

$G_m=W_m/W_m-W_w$

$G_m = \{462 / (462 - 263)\} = 462/199 = 2.322$

Step 4 Specific Gravity Test

The prime constituents such as coarse aggregates, fine aggregates, fillers and bitumen used in the bituminous concrete mix has been tabulated for evaluating the specific gravity and subsequently theoretical specific gravity (G_t) of the mix is calculated.

The test result of the sample is described below:

i. Sp. gravity of coarse aggregates, $G_1 = 2.72$

ii. Sp. gravity of fine aggregates, $G_2 = 2.72$

iii. Sp. gravity of fillers, $G_3 = 2.67$

iv. Sp. gravity of bitumen, $G_b = 1.02$

v. Wt. of coarse aggregate in the mix, $W_1 = 210.14$ g

vi. Wt. of fine aggregate in the mix, $W_2 = 615.41$ g

vii. Wt. of fillers in the mix, $W_3 = 675.45$ g

viii. Wt. of bitumen in the mix, $W_b = 75.05$ g

Evaluate the theoretical specific gravity (G_t) by using the equation.

$G_t=W_1+W_2+W_3+W_b/\{(W_1/G_1) +(W_2/G_2) +(W_3/G_3) +(W_b/G_b)\}$

$G_t = (210.14 + 615.41 + 675.45 + 75.05)/ \{(210.14/2.72) + (615.41/2.72) + (675.45/2.67) + (75.05/1.02)\}$

$G_t = 2.501$

Calculate the percentage air void (Va) by using the equation.

$Va = [(G_t-G_m)100/G_t]$

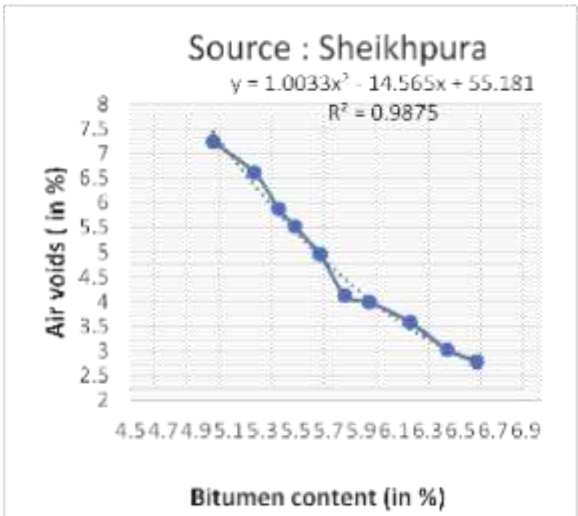
$Va = [(2.501-2.322)100/2.501]$

$Va = 7.2$ %

Table 1 Source-wise BC sample data in terms of content of bitumen vs corresponding air voids

Sample Source	Actual bitumen content by weight (in %)	Actual air voids by volume (in %)
Sheikhpura	5	7.2

Sheikhpura	5.25	6.62
Sheikhpura	5.4	5.88
Sheikhpura	5.5	5.52
Sheikhpura	5.65	4.95
Sheikhpura	5.8	4.11
Sheikhpura	5.95	3.98
Sheikhpura	6.2	3.57
Sheikhpura	6.42	3.01
Sheikhpura	6.6	2.78
Mirza chowki	5	7.08
Mirza chowki	5.2	6.23
Mirza chowki	5.32	5.1
Mirza chowki	5.4	5.42
Mirza chowki	5.55	4.98
Mirza chowki	5.75	4.43
Mirza chowki	5.8	4.22
Mirza chowki	6	4.1
Mirza chowki	6.2	4.01
Mirza chowki	6.6	3.68



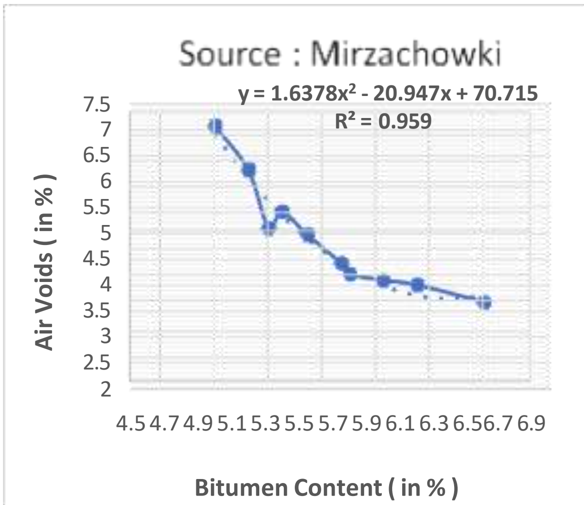


Fig. 4 Actual bitumen content vs air voids in BC samples
(a) Sheikhpura (b) Mirza chowki

The actual air voids for the sample calculated to be 7.2% with corresponding bitumen content at 5%.

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RESULTS AND ANALYSIS:

After assessing the data for establishing the relationship between actual percentage of bitumen content and air voids, 10 number of each sample have been collected from both Sheikhpura and Mirza chowki source of field. These samples have been working well in real field condition. For Sheikhpura sample the maximum and minimum value of actual volume of air voids is 7.2% and 2.78% corresponding to 5% and 6.6% binder content by weight of mix respectively. While corresponding to 5.5% content of bitumen by weight of mix, the actual air void is found to be 5.52% by volume of mix. For Mirza chowki sample the maximum and minimum value of actual volume of air voids is 7.08% and 3.68% corresponding to 5% and 6.6% bitumen content by weight of mix respectively. While corresponding to 5.4% of actual content of bitumen by weight of mix, the actual air void is found to be 5.42% by volume of mix. A regression model is developed by using the all data of air voids and bitumen content for both sources of sample. The polynomial equation is obtained for deriving percentage air voids V_a from the percentage bitumen content X. For Sheikhpura source of sample the equation is $V_a = 1.0033X^2 - 14.565X + 55.181$ and R^2 value 0.9875 concretises the model fit for validation and For Mirza chowki source of sample the equation is $V_a = 1.6378X^2 - 20.947X + 70.715$ and R^2 value 0.9598 validates the model fit for use.

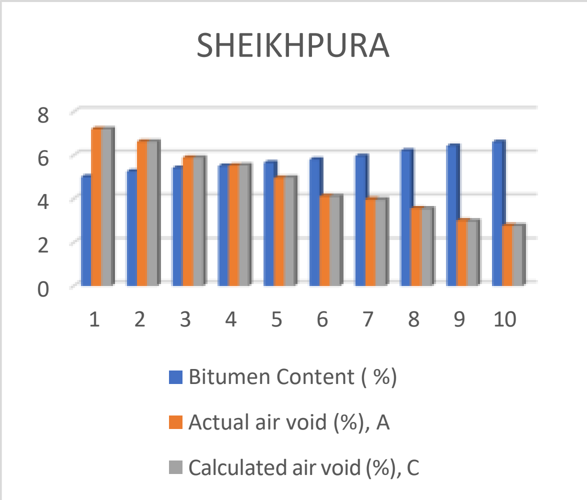
Table 2 Source-wise BC sample data actual air voids vs calculated air voids for (a) Sheikhpura and (b) Mirza chowki

Bitumen Content (%)	Actual air void (%), A	Calculated air void (%), C	Square of (C-A)	Square of (C-A)/A
5	7.2	7.2	0	0
5.25	6.62	6.62	0	0
5.4	5.88	5.88	0	0
5.5	5.52	5.54	0.0004	7.24638*10^-5
5.65	4.95	4.97	0.0004	8.08081*10^-5
5.8	4.11	4.1	0.0001	2.43309*10^-5
5.95	3.98	3.96	0.0004	1.00503*10^-4
6.2	3.57	3.55	0.0004	1.12045*10^-4
6.42	3.01	2.98	0.0009	2.99003*10^-4
6.6	2.78	2.77	0.0001	3.59712*10^-5

(a) Sheikhpura

Bitumen Content (%)	Actual air void (%), A	Calculated air void (%), C	Square of (C-A)	Square of (C-A)/A
5	7.08	7.08	0	0
5.2	6.23	6.23	0	0
5.32	5.1	5.12	0.0004	7.84314*10^-5
5.4	5.42	5.44	0.0004	7.38007*10^-5
5.55	4.98	4.96	0.0004	8.03213*10^-5
5.75	4.43	4.42	0.0004	2.25734*10^-5
5.8	4.22	4.2	0.0004	9.47867*10^-5
6	4.1	4.09	0.0001	2.43902*10^-5
6.2	4.01	4	0.0001	2.49377*10^-5
6.6	3.68	3.67	0.0001	2.71739*10^-5

(b) Mirza chowki



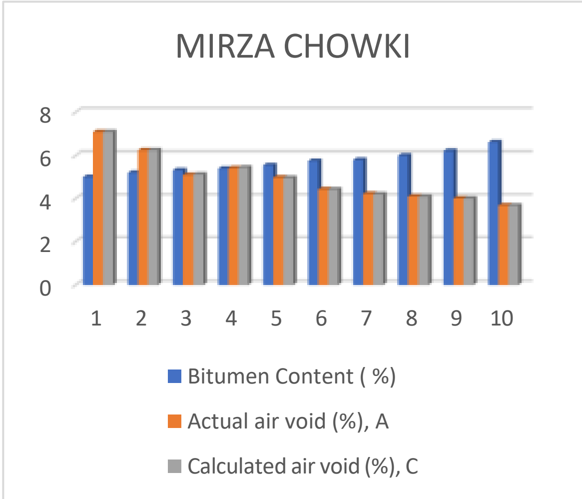


Fig. 5 3-D bar chart of actual and calculated air voids percent with varying percent of bitumen
(a) Sheikhpura (b) Mirza chowki

The above specimen is used for the validation of the model, for that it has been tabulated for the extent of variance by using chi- square test. After analysing the trend of data, it can easily be detected the strong indication of high confidence value. Also, the data for sample is independent to each other. For enhancement of the validity between actual and theoretical content of bitumen, the hypothesis is most suitable to be tested by chi- square test.

CONCLUSIONS:

The actual content of bitumen and air voids of the mix is simulated using 20 bituminous concrete mix samples taken from the field. After comparing the data, it is easily concluded that air void decreases with increase in actual content of bitumen and its vice-versa but after a certain point of bitumen content value almost equals to the percentage air voids. The above scenario is found to be same for both source of HMA sample which demonstrates the inverse relationship between percentage air voids and bitumen content. As per MoRTH specification the desirable value for designed percentage air voids for BC must be in the range of 3% to 5%. But recent research suggests that there is a need to increase the design value of percentage air voids for better attainment of performance in the mix, it is essential to readjust the minimum content of bitumen as per provision of code. According to the current scenario it is 5% by weight in case of BC as per clause No. 508 of IRC, 2001 ‘‘Specification for Road and Bridge Works (Fourth Revision)’’ (IRC, 2001) [21]. With this effect if minimum percentage of bitumen reduces then it will reduce the consumption of bitumen and drastically reduce the cost of construction and also achieves better performance and makes the construction economical too.

After analysing all the points, below are the conclusions drawn up to a certain degree of precision:

i. The value of actual content of air void is different than the air void suggested in design because the degree of compactive effort actually on the HMA layer and in the laboratory mix, makes recognizable difference.

ii. It is clearly notified that the inverse relation between air voids and bitumen content i.e. increase in actual bitumen content with decrease in percentage air voids and vice-versa.

iii. As many researchers suggest for increment in the design value of air voids by at least 1% i.e. up to 5% from current exercise of 4% for better attainment of performance in the mix [9,19].

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